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ANTITUBERCULAR COMPOUNDS

Part II. * 3: 5-Diiodo-4-aminosalicylic Acid, 4-Amino-*O*-acetylsalicylic Acid and Other Derivatives of 4-Aminosalicylic Acid

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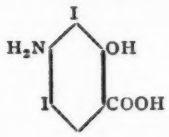
Because of its low toxicity and usefulness in the treatment of tuberculosis, 4-aminosalicylic acid (PAS) has attracted wide interest, directed towards its synthesis by different methods,[1,2] estimation,[3] pharmacology,[4] preparation of derivatives[5] and the study of compounds analogous to it.[6] With a view to obtain drugs more potent than PAS, numerous derivatives of PAS have been prepared, but none has been found to surpass PAS in *in vivo* activity. A method for the synthesis of PAS from 4-nitro-*o*-toluidine has been described by us[1] and it was shown that this route has the advantage of the accessibility of certain derivatives of PAS. Thus, 3: 3′-dihydroxyazobenzene-4: 4′-dicarboxylic acid was synthesized,[1] while the preparation of 4-amino-*O*-acetylsalicylic acid (aminoaspirin) is now reported.

Among the few nuclear substituted derivatives of PAS so far recorded, 3: 5-dibromo-PAS has been described by Drain *et al.*[5b] and Hirst and Hurni.[5d] The latter workers have determined its inhibition concentration (12·5–6·25), which is much higher than that of PAS (0·0487–0·0293). Diiodosalicylic acid is more stable[7] *in vivo* and *in vitro* and is a more potent antibacterial agent than the corresponding dibromosalicylic acid[8]; Küster and Wagner-Jauregg[9] have shown that sodium 5-iodosalicylate and 3 : 5-diiodosalicylate are bactericidal to acid-fast bacteria, being 1·25 and 4·5 times as active as chaulmoogric acid against tubercle bacilli. Izzo and Cicardo[10] have also found that the injection of thyroxine into guinea pigs infected with tubercle bacilli produces a considerable prolongation of life, whereas thyroid-ectomized guinea pigs have a very much lower resistance to tuberculosis. For these reasons, 3: 5-diiodo-4-aminosalicylic acid (I) has been prepared by us by the action of iodine monochloride on PAS in glacial acetic acid. The sodium salt is moderately soluble in water. When boiled with dilute hydrochloric acid, (I) decomposes to *m*-aminophenol with the liberation of iodine

* The paper on "3 : 3′-Dihydroxyazobenzene-4 : 4′-dicarboxylic acid and 4-aminosalicylic acid" (*Proc. Ind. Acad. Sci.*, 1949, **29 A**, 196) is to be regarded as Part I of the series.

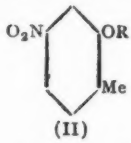
and carbon dioxide, but is unaffected by boiling with water. Because of the iodine atoms adjacent to the amino group, (I) can only be diazotized



(I)

under special conditions such as the addition of solid sodium nitrite to a solution in concentrated sulphuric acid. *In vitro* tests by Prof. B. V. Bhide, to whom our thanks are due, have shown that (I) inhibits the growth of tubercle bacilli up to a concentration of 1 : 5000 only. In view of the low toxicity of PAS and the readiness with which iodine is liberated from (I), tests on (I) in intestinal infections have been instituted.

Although many functional derivatives of PAS have been reported by various workers, little attention seems to have been paid to the synthesis of its ethers and *O*-acyl derivatives. 4-Amino-*O*-acetylsalicylic acid has now been obtained by catalytic reduction of *O*-acetyl-4-nitrosalicylic acid.[1] The compound is stable under anhydrous conditions and can be dried at 120° without decomposition. It is deacetylated on warming with 5% aqueous sodium hydroxide. Ethers (IV, R = Me, Et and *n*-C_4H_9) have been prepared by catalytic reduction of *O*-alkyl derivatives (III) of 4-nitrosalicylic acid, obtained by the oxidation of the corresponding ethers (II) of 4-nitro-*o*-cresol. The yield of the *O*-alkyl derivatives obtained by the oxidation of



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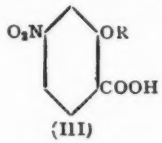

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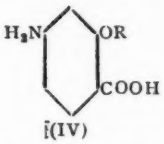
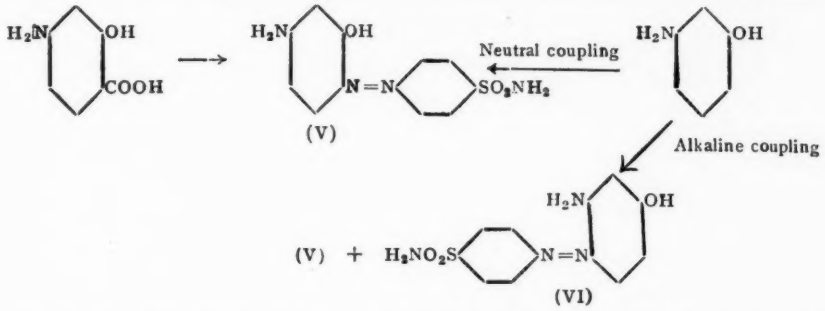


(IV)

(II) considerably diminishes with increase in the length of the alkyl chain. The methyl ester of (IV; R = Me) has also been prepared. The methyl, ethyl and *n*-propyl esters of PAS were obtained from the corresponding esters of 4-nitrosalicylic acid by catalytic reduction.[5a] The synthesis of other esters of PAS was not undertaken, since Drain *et al.*[5b] and Rosdahl *et al.*[5c] have reported the preparation of a series of esters by the same method. Shaefer and Doub[5f] have esterified PAS directly in 70% yield by using boron trifluoride as catalyst. Most of these esters of PAS have about the same bacteriostatic effect as the free acid.[5c]

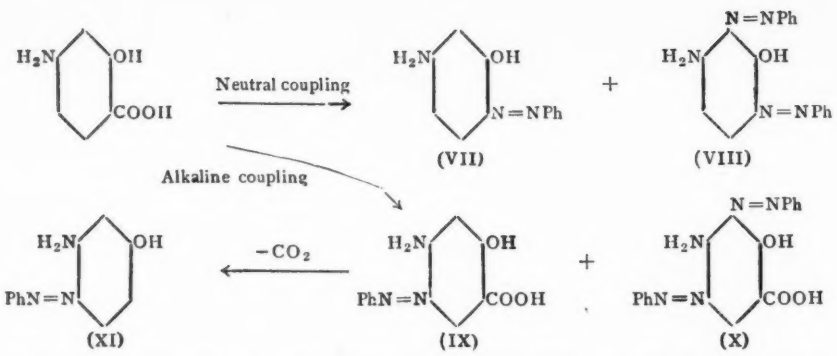
The coupling behaviour of diazotized PAS towards phenolic components has already been reported by us.[1] A study of its coupling be a iour towards

diazonium salts was considered to be of interest since the procedure is employed in its estimation in body fluids.[3] When diazotized sulphanilamide was coupled with PAS in alcoholic sodium acetate solution, a dye (A), m.p. 236°, insoluble in sodium bicarbonate solution, was obtained.[5a] The properties of the dye indicated decarboxylation, and it was identical with the dye obtained by coupling *m*-aminophenol with diazotized sulphanilamide under similar conditions. The alkaline coupling of *m*-aminophenol with one mol. of diazotized sulphanilamide gave a mixture of dyes which were separated from acetone solution by chromatographic adsorption on alumina into two fractions: one melting at 236° and the other (B) at 224°. The dye, m.p. 236°, was weakly adsorbed on the alumina column and was identical



with the dye (A) obtained by neutral coupling of PAS. The formation of the dye (A) under neutral conditions, its chromotographic behaviour and other properties indicated it to be 4-amino-2-hydroxyazobenzene-4′-sulphonamide (V); whereas the dye (B), strongly adsorbed on alumina, must be 2-amino-4-hydroxyazobenzene-4′-sulphonamide (VI). The dyes (V) and (VI) have been described in an I.G. Patent,[11] but the melting points quoted for them are 228° and 106° respectively.

In order to examine more closely the decarboxylation of PAS during diazonium coupling, PAS was coupled with one mol. of diazotized aniline under neutral conditions. In this case also decarboxylation occurred, and a monoazo dye, m.p. 124°, accompanied by a small amount of a *dis*azo dye, m.p. 179-80°, was obtained. The monoazo dye was sparingly soluble in 2% caustic soda solution and largely retained in the ether layer when an ether solution was shaken with aqueous caustic soda, indicating the presence of a hydroxyl group *ortho* to the azo group. Alkaline coupling of PAS with one mol. of diazotized aniline, however, yielded 4-amino-5-benzeneazosalicylic acid (IX), m.p. 223°, together with a small amount of 4-amino-3: 5-*bis*benzeneazosalicylic acid (X), m.p. 256°. The dye (IX) could be smoothly



decarboxylated to 2-amino-4-hydroxyazobenzene (XI), m.p. 187°; the constitution of the monoazo dye, m.p. 124°, obtained by neutral coupling of PAS, was therefore 4-amino-2-hydroxyazobenzene (VII). For final confirmation of the constitutions of the monoazo dyes (VII and XI), their preparation from *m*-aminophenol was necessary. *m*-Aminophenol was coupled with one mol. of diazotized aniline in neutral as well as alkaline conditions. Under either condition a mixture of dyes was formed. They were separated from their benzene solution by chromatographic adsorption on alumina and elution with the same solvent. 4-Amino-2-hydroxyazobenzene (VII) was weakly adsorbed owing to the chelation of the hydroxyl and azo groups, whereas 2-amino-4-hydroxyazobenzene (XI) was retained at the top of the column as expected. In neutral coupling, the dye (VII) was formed in major yield, whereas in alkaline coupling both were formed in almost equal quantities. The visual colour, mode of formation, chromatographic behaviour, alkali-solubility and coloration with concentrated sulphuric acid of the dyes (VII) and (XI) were very similar to the properties of the dyes (V) and (VI) respectively, obtained from PAS and sulphanilamide.

The lower m.p. of the *dis*azo dye obtained in the neutral coupling of PAS with diazotized aniline in comparison with (XI) indicated its constitution as 3-amino-2: 6-*bis*benzeneazo-phenol (VIII).

Thus, the coupling of PAS with diazotized sulphanilamide and aniline under neutral conditions takes place with displacement of the carboxyl group; but coupling takes place normally under alkaline conditions. On treatment with only one mol. of diazotized aniline PAS forms *dis*azo dyes simultaneously with monoazo dyes.

Experimental

3: 5-*Diiodo*-4-*aminosalicylic acid* (I).—A solution of 4-aminosalicylic acid (5·0 g., 0·0326 mole) in glacial acetic acid (250 c.c.) was treated with

iodine monochloride (9·72 g., 0·0598 mole) in glacial acetic acid (30 c.c.) under mechanical stirring. During addition of iodine monochloride a precipitate appeared; water (150 c.c.) was then added when further precipitation occurred. The reaction mixture was gradually heated to 55–60° on the water-bath during 20 minutes and maintained at this temperature for further 20 minutes. After cooling to room temperature the reaction mixture was filtered. The product was washed with water, extracted with 1% sodium bicarbonate solution and the solution acidified with acetic acid. The precipitate was collected and dried (11·0 g.). 3:5-Diiodo-4-aminosalicylic acid crystallizes from alcohol in colourless flat needles, which decomposed at 174° with liberation of iodine vapour (Found: C, 20·9; H, 1·4; N, 3·3; I, 62·3; Equiv. wt., 397. $C_7H_5I_2NO_3$ requires, C, 20·7; H, 1·2; N, 3·4; I, 62·4%; Equiv. wt., 405). The compound is insoluble in water, but moderately soluble in alcohol and acetic acid, and sparingly soluble in acetone and benzene. It decomposes with liberation of iodine, when boiled with 8% hydrochloric acid. With alcoholic ferric chloride it gives a violet colouration. With concentrated sodium bicarbonate solution it forms an insoluble sodium salt, which dissolves on dilution. The sodium salt crystallizes from water, in which it has a solubility of about one in 60 at room temperature.

O-Acetyl-4-aminosalicylic acid.—A solution of the freshly prepared acetate of 4-nitrosalicylic acid, m.p. 156° (1·5 g.) in absolute alcohol (5 c.c.) was shaken with hydrogen under 40 lb. pressure and Raney nickel for half an hour. The residue obtained after filtration of the catalyst and distillation of alcohol under reduced pressure at 60° from the filtrate, crystallized from a mixture of ether and *n*-hexane in colourless plates, m. p. 225° (decom.) (Found; C, 55·4; H, 4·8; N, 7·4. $C_9H_9NO_4$ requires C, 55·4; H, 4·6; N, 7·2%). The substance is very soluble in alcohol, ether and acetone but sparingly soluble in water, benzene and petroleum-ether. The alcoholic solution gives a very faint brown colouration with alcoholic ferric chloride. The compound is deacetylated by treatment with 5% caustic soda solution at room temperature for 60 hours.

Methyl ether of 4-aminosalicylic acid.—4-Nitro-2-methoxybenzoic acid, m.p. 147° (3·0 g.) obtained by the method of Simonsen and Rau,[12] was reduced by shaking with hydrogen at 40 lb. pressure in the presence of Raney nickel (about 0·2 g.) for 2 hours. The catalyst was filtered off and alcohol removed under reduced pressure, when the ether separated in colourless needles. It was crystallized from methanol in plates, m.p. 153° (Found: C, 57·8; H, 5·5; N 8·6. $C_8H_9NO_3$ requires C, 57·5; H, 5·8; N, 8·4%). Froeliches and Cohen[16] quote m.p. 217–8°.

A similar catalytic hydrogenation of methyl-4-nitro-2-methoxybenzoate, m.p. 89° (Simonsen and Rau[12] record the same m.p.) gave *methyl-4-amino-2-methoxybenzoate*, which crystallized from alcohol in plates, m.p. 157–58° (Found: N, 7·8. $C_9H_{11}NO_3$ requires N, 7·7%).

4-*Nitro*-2-*ethoxytoluene*.—To sodium ethoxide (24 c.c. alcohol and 0·9 g. sodium) was added 4-nitro-*o*-cresol (6·0 g.) and the mixture warmed on the water bath. An excess of ethyl bromide (12·0 cc.) was then added and the mixture refluxed until it gave no test for alkalinity (litmus). Alcohol and unreacted ethyl bromide were removed under reduced pressure and the residue was extracted with 5% sodium hydroxide solution to remove any unreacted cresol. 4-Nitro-2-ethoxytoluene crystallized from 70% alcohol (Norit) (6·2 g; 93% yield), in colourless needles, m.p. 56–58° (Spiegel *et al.*[13] who prepared the compound by using ethyl iodide quote m.p. 61°) (Found: N, 7·8. $C_9H_{11}NO_3$ requires N, 7·7%). 4-Nitro-2-ethoxytoluene has also been obtained in 85-90% yield by direct ethylation of 4-nitro-*o*-cresol with ethyl sulphate in alkaline medium at 50–60° temperature.

4-*Nitro*-2-*n-butoxytoluene* obtained by the alkyl bromide method crystallised from 70% alcohol in long needles, m.p. 48° (Found: N, 7·2. $C_{11}H_{15}NO_3$ requires N, 6·7%).

4-*Nitro*-2-*ethoxybenzoic acid*.—To 4-nitro-2-ethoxytoluene (4·0 g.) in boiling water (50 cc.) containing magnesium sulphate (12·0 g.) was added under mechanical agitation, potassium permanganate solution (250 c.c., 4% solution) in small quantities during 2 hours. Boiling was continued for a further 1½ hours. Excess of potassium permanganate was destroyed by adding a few drops of alcohol and the reaction mixture filtered while hot. The precipitate was washed with hot water and the filtrate and washings acidified with hydrochloric acid. The precipitated acid was filtered and purified by treatment with sodium bicarbonate solution. It crystallized from water in colourless elongated plates (0·6 g.) m.p. 148° (Found: N, 6·6. $C_9H_9NO_5$ requires N, 6·6%).

4-*Nitro*-2*n-butoxybenzoic acid* similarly prepared, crystallized from 80% alcohol in plates, m.p. 125° (Found: N, 6·3. $C_{11}H_{13}NO_5$ requires N, 5·9%).

The ethyl and n-butyl ethers of 4-*aminosalicylic acid* were obtained from the corresponding nitro compounds by reduction, similar to that of 4-nitro-2-methoxybenzoic acid described earlier. The former crystallized from methanol in colourless plates, m.p. 151° (Found: N, 7·9. $C_9H_{11}NO_3$ requires N, 7·7%); and the latter from methyl alcohol in plates, m.p. 167° (decomp.) (Found: N, 6·7. $C_{11}H_{15}NO_3$ requires N, 6·7%).

Methyl 4-aminosalicylate.—A solution of methyl 4-nitro-salicylate, m.p. 97°[5a] (1·5 g.) in benzene (15 c.c.) was shaken with hydrogen under 40 lb. pressure and Raney nickel for one hour. The residue obtained after filtration of the catalyst and removal of benzene from the filtrate crystallized from a mixture of benzene and *n*-hexane in colourless prisms, m.p. 120–1° (118°, 120–1° and 121–2° in references 5*c*, 5*b* and 5*f* respectively) (Found: N, 8·4. $C_8H_9NO_3$ requires N, 8·3%).

Ethyl-4 aminosalicylate crystallized from benzene-hexane in colourless needles, m.p. 114–15° (115°, 111·5–113° and 114–5° in references 5*c*, 5*b* and 5*f* respectively) (Found: N, 7·6. $C_9H_{11}NO_3$ requires, N, 7·7%). n-*Propyl-4-aminosalicylate* crystallized from benzene-hexane in colourless needles, m.p. 102–4° (102–3° and 102–3° in references 5*c* and 5*b* respectively) Found: N, 7·0. $C_{10}H_{13}NO_3$ requires N, 7·2%).

Coupling of 4-aminosalicylic acid with diazotized sulphanilamide under neutral conditions and formation of 4-amino-2-hydroxyazobenzene-4′-sulphonamide (*V*).—A solution of 4-aminosalicylic acid (0·77 g.; 0·005 mole.) in alcohol (20 c.c.) and sodium acetate solution (6·0 g. in 20 c.c. water) was treated with the diazonium solution obtained from sulphanilamide (0·7 g.; 0·005 mole.). After stirring for half an hour, the dye was filtered and crystallized from 60% alcohol. The long orange-red needles had m.p. 236° (Found: N, 18·4. $C_{12}H_{12}N_4O_3S$ requires N, 18·4%). The dye is insoluble in sodium bicarbonate solution, but soluble in caustic soda and sodium carbonate solutions, and when mixed with the dye obtained by coupling *m*-aminophenol with diazotized sulphanilamide in alcoholic sodium acetate solution (see below) showed no depression in m.p. It gives a yellow colouration with concentrated sulphuric acid.

Coupling of m-*aminophenol with diazotized sulphanilamide under neutral conditions.*—On coupling in alcoholic sodium acetate solution with diazotized sulphanilamide, *m*-aminophenol gave a dye which crystallized from 60% alcohol in orange-red needles, m.p. 236° (Found: N, 18·4. $C_{12}H_{12}N_4O_3S$ requires N, 18·4%).

Coupling of m-*aminophenol with diazotized sulphanilamide under alkaline condition and formation of 2-amino-4-hydroxyazobenzene-4′-sulphonamide* (*VI*).—To a mechanically stirred solution of *m*-aminophenol (2·18 g.) in 2% caustic soda solution (200 c.c.) maintained at 0° was added the diazonium solution prepared from sulphanilamide (3·44 g.). The reaction mixture was stirred for half an hour and acidified with acetic acid. The precipitate was collected and dried at about 80°, when the red dye became much darker in colour. The dye was insoluble in benzene, *n*-hexane, carbon tetrachloride,

toluene, ether and chloroform, slightly soluble in boiling water and moderately soluble in acetone, alcohol and acetic acid. An acetone solution of the dye was chromatographed on a column of alumina. The chromatogram was developed with alcohol-acetone (1 : 4) when two bands appeared: an upper orange band and a lower yellow band. The lower band was eluted with alcohol-acetone, and the upper was extracted with boiling alcohol. On working the alcohol-acetone solution, a dye, m.p. 236°, was obtained; while the residue obtained on distillation of the alcohol extract of the upper band yielded after crystallization from water, yellow plates, m.p. 224° (Found: N, 18·7. $C_{12}H_{12}N_4O_3S$ requires N, 18·4%). The dye gives an orange colouration with concentrated sulphuric acid.

Coupling of 4-aminosalicylic acid with diazotized aniline under neutral conditions and formation of (VII).—To a mechanically stirred solution of 4-aminosalicylic acid (1·53 g., 0·01 mole.) in alcohol (40 c.c.), water (30 c.c.) and sodium acetate solution (6·0 g. in 20 c.c. water) at 0° was added a diazonium solution prepared from aniline (0·93 g., 0·01 mole.). The reaction mixture was stirred for half an hour and diluted with water (100 c.c.). The reddish orange dye was filtered, washed with water and taken up in ether. The ethereal solution was extracted successively with 5% sodium bicarbonate solution and 5% sodium hydroxide solution. On acidifying the latter extract with acetic acid, a dye separated, which crystallized from dilute alcohol in reddish orange needles, m.p. 124° (Found: N, 19·4. $C_{12}H_{11}N_3O$ requires N, 19·7%). It forms a yellow solution in concentrated sulphuric acid.

Evaporation of the ether, from which the alkali-soluble dye had been extracted, gave a crystalline residue, which on recrystallization from 60% alcohol yielded shining brown plates, m.p. 179–80° (Found: N, 22·4. $C_{18}H_{15}N_5O$ requires N, 22·1%). The dye gives a bordeaux-red colouration with concentrated sulphuric acid.

Coupling of 4-aminosalicylic acid with diazotized aniline under alkaline condition and formation of 4-amino-5-benzeneazosalicylic acid (IX).—Aniline (1·86 g.), in a mixture of concentrated hydrochloric acid (6 c.c.) and water (6 c.c.) was diazotized with a solution of sodium nitrite (1·6 g.) in water (10 cc.) at 0°. The solution was then slowly added to a mechanically stirred, cold solution of 4-aminosalicylic acid (3·16 g.) dissolved in 10% sodium hydroxide solution (50 c.c.) and water (40 c.c.). The temperature of the reaction mixture was kept below 5° by external cooling. On addition of the diazonium solution coupling began immediately with the development of a red colour. After the addition of the diazonium solution was over, stirring was continued for one hour. The reaction mixture was then filtered, and the residue washed

with water. Crystallization from 80% acetic acid gave a brown dye, m.p. 256° (decomp.) (Found: N, 19·3. $C_{19}H_{15}N_5O_3$ requires N, 19·3%). The dye gives a pure green colouration with concentrated sulphuric acid.

Acidification of the filtrate with acetic acid gave the dye (IX) which on repeated crystallizations from 50% alcohol (norit) was obtained as long yellow needles, m.p. 223° (decomp.) (Found: N, 16·6. $C_{13}H_{11}N_3O_3$ requires N, 16·3%). The dye forms an insoluble sodium salt in 10% sodium bicarbonate solution, which dissolves on dilution. It gives an orange colouration with concentrated sulphuric acid.

Decarboxylation of (*IX*).—The acid (IX) (40 mg.) was suspended in glycerol (10 c.c.) and the mixture heated for 20 minutes in a glycerol bath at 180°. The dye slowly dissolved in glycerol and evolution of gas was perceptible during heating. The reaction mixture was then cooled and diluted with water (40 c.c.) when a crystalline dye separated. It was filtered and crystallized from dilute alcohol, m.p. 187°.

Coupling of m-*aminophenol with diazotized aniline under neutral conditions and formation of* (*VII*) *and* (*XI*).—The dye obtained by adding diazotized aniline (0·93 g.) to a solution of *m*-aminophenol (1·09 g.) in alcohol (30 c.c.) and sodium acetate solution (6 g. in 20 c.c. water), was dissolved in benzene and chromatographed on a column of alumina. Using the same solvent for development of the chromatogram, two bands appeared: an upper orange-coloured band and a lower yellow band. The alumina column was taken out and the two zones were separated. Extraction of the upper portion with alcohol, partial evaporation of the solvent and dilution with water yielded golden yellow plates, m.p. 187°. The m.p. of this dye admixed with the dye obtained by decarboxylation of (IX) was not depressed (Found: N, 19·4. $C_{12}H_{11}N_3O$ requires, N, 19·7%). Similar treatment of the lower part of the alumina column gave bright orange needles, m.p. 124° (Found N, 19·4. $C_{12}H_{11}N_3O$ requires N, 19·7%). The m.p. of the latter dye was not depressed by admixture with the monoazo dye obtained by coupling PAS with diazotized aniline in alcoholic-sodium acetate solution, described earlier. This dye gives with concentrated sulphuric acid a yellow colouration, and the dye m.p. 187°, an orange colouration.

Coupling of m-*aminophenol with diazotized aniline under alkaline conditions.*—On coupling in 2% caustic soda solution with diazotized aniline, *m*-aminophenol gave a mixture of dyes, m.p. 124° and m.p. 187°, in nearly equal proportion. The two dyes were separated by chromatographic adsorption as described in the previous experiment.

Summary

3 : 5-Diiodosalicylic acid, 4-amino-*O*-acetylsalicylic acid (aminoaspirin), and a series of ethers of 4-aminosalicylic acid have been prepared.

The behaviour of 4-aminosalicylic acid towards diazonium salts has been investigated.

Acknowledgment

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SOME NEW CONSIDERATIONS IN THE BIOGENESIS OF SAP-SOLUBLE PIGMENTS

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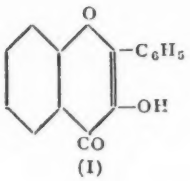
Just like the components of blood for animals, the sap-soluble pigments (anthoxanthins and anthocyanins) should be of importance for the physiology of plants though adequate information is not available about the part they play. Szent-Gyorgyi[1] considered that hydroxy-flavones play an important part as components of oxidation-reduction systems. Suggestions have also been made that the pigments control light absorption in the growing parts, leaves and flowers and thus regulate photosynthesis. That some of them have hormonal properties was shown by Kuhn and Low.[2] But it seems to be definitely established that they are closely connected with the individual characteristics of a plant and the occurrence and details of the constitution of the different pigments are genetically controlled. As far as human interest is concerned, the anthocyanins have an æsthetic appeal and are of value in horticulture whereas the anthoxanthins used to be valued as mordant dyes. With the advent of synthetic dyes this value of anthoxanthins has ceased to exist, but more recently they have been found to have definite physiological effects on the animal system and may continue to elicit interest for this reason. To the plant-breeder the study of these pigments provides great help in the study of genetics.

Among the sap-soluble pigments containing the C_{15} skeleton the following represents the arrangement of groups based on the state of oxidation of the oxygen ring: (1) flavonols (highest) (I); (2) flavones (II), flavanonols (III), anthocyanidins (IV), and isoflavones (V); (3) flavanones (VI), and chalkones (VII); (4) catechins (VIII) and phloretin (IX). Any general theory should embrace all these different but closely related groups.

In the study of the biogenesis of the sap-soluble pigments attention was given earliest to the association of flavonols and anthocyanins and it was considered that the latter were derived from the former; chemically a process of reduction was needed and it could be carried out *in vitro*. But this theory of sequential origin could not be supported because of the lack of correlation in the structures of the flavonols and anthocyanins occurring together in the same source. Further in some cases the accompanying anthoxanthins were not flavonols but flavones; for example in the flowers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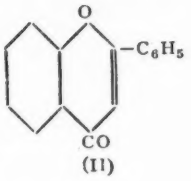
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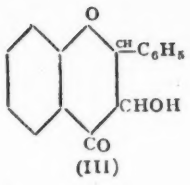
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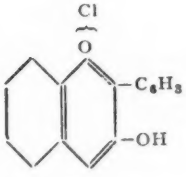
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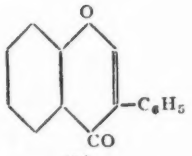
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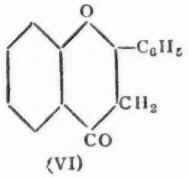
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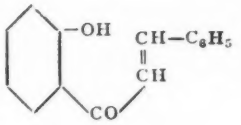
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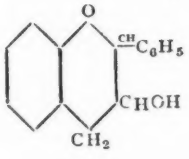
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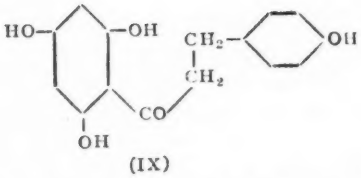
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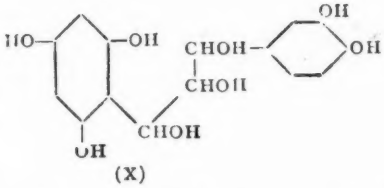
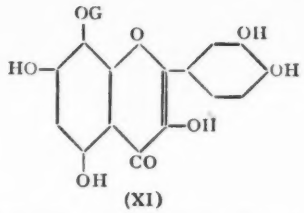

(X)

of *Antirrhinum majus* the flavones apigenin and luteolin accompany the anthocyanin, a cyanidin glycoside. The relation between flavones and anthocyanidins (3-hydroxy compounds) is not so direct and a number of intermediate stages will have to be postulated for the transformation of one into another. These difficulties were removed by the theory of parallel origin from a common precursor (X) as proposed by Robinson.[3] Some of the implications of the theory have been examined by making a survey of anthocyanins[4] and by a study of flavones and flavonols[5] and the results are confirmatory. Though the results of investigations in the field of genetics are in accord with this theory, the alternative of sequential evolution cannot be excluded. The position seems to be best summed up in the words of Stephens[6]: "Parallel syntheses of these structurally similar pigments would surely require that the genes controlling these syntheses should be extremely specific in their actions. Otherwise a gene responsible for a

particular substitution in an anthocyanin molecule might be expected to bring about a similar substitution in the accompanying anthoxanthin. However if this situation is avoided by postulating extreme specificity of the genes, the whole argument in favour of parallel syntheses is much weakened. A situation involving sequential synthesis might be equally probable. For example, a certain genotype might contain specific genes for converting quercetin into cyanidin, and in addition a specific gene for methylating the cyanidin nucleus. In that case one would not necessarily expect quercetin to be accompanied by cyanidin in the same flower, since the cyanidin might easily be converted into a methylated form (that is, peonidin) as fast as it was formed. It seems therefore that a critical discrimination between the alternative hypotheses of parallel or sequential syntheses must await more information on the specificity of the genes concerned ".

As already mentioned these studies in biogenesis should be extended to embrace all the groups of sap soluble pigments in order to get a complete picture. The new considerations that are discussed in the present paper seem to indicate clearly that the process of sequential evolution does exist to a limited extent and should be considered as playing a part along with the process of parallel evolution. These relate to the occurrence of methyl ethers and glycosides of anthoxanthins. The position occupied by ether and glycoside groups varies and practically all positions are known to be capable of being involved. No precise information seems to be available as to why and how the choice of particular positions is made in nature in individual cases though the question is quite important. The following seem however to indicate the possible reasons: (1) solubility, (2) light absorption and (3) stability to oxidation. As an example gossypin[7] (XI) (8-glucoside of gossypetin) and gossypitrin[8] (7-glucoside) (XII) can be compared. The former is readily soluble in water whereas the latter is not. Further gossypin is more deeply yellow. It is also more stable to oxidation since the quinol structure is protected. Stability to oxidation is a particularly important consideration. Where there are a large number of phenolic hydroxyl groups especially in *ortho* or *para* orientation, oxidation can take place readily and this can be conrolled to a considerable extent by glycoside or ether formation. To these three reasons may be added a fourth. The physiological properties of the compounds seem to be also affected markedly by these modifications.

A question which has been raised in regard to them is whether glycoside formation and similarly ether formation represent final stages in evolution or whether they take place even earlier. These reactions are definitely genetically controlled and in most cases the glycosides and the aglucones



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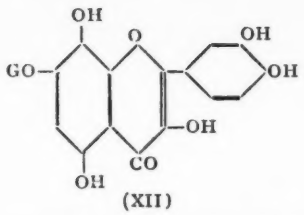
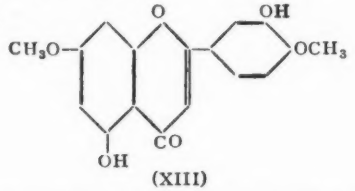


(XII)

and similarly the methyl ethers and the parent hydroxy compounds occur together. Armstrong and Armstrong in their monograph on Glycosides came to the conclusion that glycoside formation is the final stage. Stephens[9] working from the side of genetics has also arrived at the same result. Even this seems to require some modification in the light of the chemical considerations discussed below.

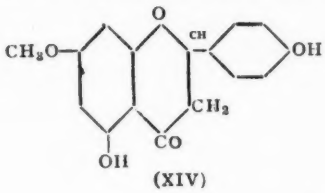
7-Methyl ethers of flavones and flavonols are of frequent occurrence and so also are 7-glycosides. This may indicate either that the 7-hydroxyl is markedly more reactive than the rest or that there is an efficient mechanism for protecting the other positions. Very little is known about the second alternative except that the 5-position is definitely protected by chelation with the neighbouring carbonyl. In the simple dihydroxy flavone, chrysin, the 7-hydroxyl is far more reactive than the 5- for this reason and partial methylation or glycosidation readily takes place. But as soon as fresh hydroxyls are introduced in the pyrone ring and side phenyl nucleus, the difference between the 7- and other positions becomes much less marked. Perkin and Horsfall[10] made attempts to prepare a monomethyl ether of luteolin by direct methylation and recorded that they could get only the 7: 4′-dimethyl ether (XIII) in a small yield. It is therefore clear that direct partial methylation or glycoside formation of flavones and flavonols in the 7-position is not a successful one in the laboratory and cannot be expected to be successful even in the plant.



(XIII)

The possible explanation of the occurrence of 7-methyl ethers of hydroxy flavones is suggested by certain recent laboratory work. (1) The bark of *Prunus puddum*[11] contains three closely related 7-methyl ethers (i) sakuranetin (XIV), (ii) genkwanin (XV) and (iii) prunetin (XVI) which form a significant association. Sakuranetin and sakuranin have been known to occur

in various species of *Prunus* and so also prunetin and its glucoside. But the discovery of (i) and (iii) occurring together and along with genkwanin is new. (2) It has also been shown[12] that with hydroxy flavanones (*e.g.*, naringenin XVII) and isoflavones (*e.g.*, genistein XVIII) partial monomethylation of the 7-position can be carried out.



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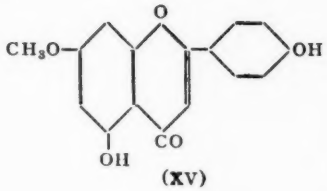

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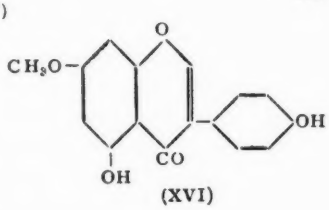

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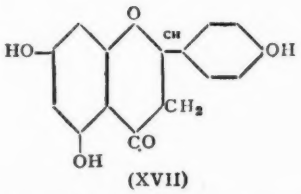
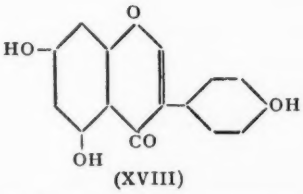


(XVII)

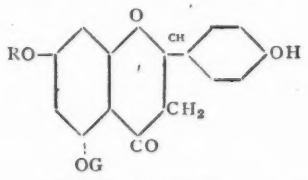


(XVIII)

The markedly higher reactivity of the 7-hydroxyl as compared with the others is inherent in the structure of these flavanone and isoflavone molecules. The carbonyl group activates the 7-hydroxyl by electromeric polarisation and deactivates the 5-hydroxyl by chelation, the hydroxyls in the side phenyl nucleus not being affected. It is relevant to mention here that Zemplen, *et al.*[13] have successfully prepared hesperidin (7-glycoside) from the flavanone hesperetin and genistin (7-glucoside) from the isoflavone genistein. (3) A third useful observation is that flavanones can be readily oxidised by mild oxidising agents[14] (iodine in the presence of sodium acetate) to the corresponding flavones. Taking all the three together the correct explanation of the origin of genkwanin could be derived. It cannot be obtained by the direct methylation of apigenin, but can be prepared by the oxidation of sakuranetin along with which it occurs in the plant, and sakuranetin is the direct product of the monomethylation of naringenin. The scheme is as follows: XVII → XIV → XV. It would mean acceptance of the sequential evolution of 7-methoxy flavones from the corresponding flavanones and that methylation is not always the last stage in evolution.

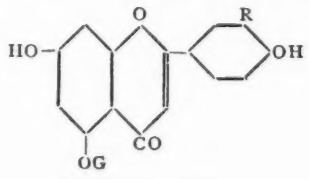
The above mentioned occurrence of the isoflavone (prunetin) along with its isomeric flavone (genkwanin) is a rare example of such association. It is obviously a result of parallel evolution, sakuranetin forming an intermediate stage for genkwanin. The same genetic factor could then be responsible for the methylation in both cases since in regard to this reaction prunetin and sakuranetin are very similar.

A similar position requiring special explanation is created by the discovery of glycosides with the sugar groups in the difficultly accessible 5-position of flavones and flavanones. Examples are: (1) salipurposide, 5-glucoside of naringenin[15] (XIX, R = H); (2) sakuranin, 5-glucoside of sakuranetin[16] (XIX, R = CH_3); (3) galuteolin,[17] luteolin-5-glucoside (XX, R = OH) and (4) apigenin-5-glucoside[18] (XX, R = H). It will be quite unacceptable to suggest direct entry of the sugar groups as the last stage in the formation of these compounds. A reasonably correct explanation is indicated by the presence of sugar groups in a corresponding position (6-position) in isosalipurposide (XXI),[19] phloridzin[20] (XXII, R = H) and asebotin[21] (XXII, R = CH_3). In the case of these compounds in which the oxygen ring has not been closed up, the 6-position can be reactive and direct glycoside formation can take place. This can happen even when there is a carbonyl group since it can deactivate only one *ortho*-hydroxyl group. It could therefore be suggested that glycoside formation in the 6-position takes place at an earlier stage and the flavanone ring is subsequently formed leading to the production of a 5-glycoside (XIX). In this connection the occurrence in *Salix purpurea* of isosalipurposide (XXI) is of some significance as it may indicate an intermediate stage in the formation of salipurposide in the same plant. But it may not be correct to say that glycoside formation takes place at the chalkone stage, because it has been shown[22] that chalkones with free

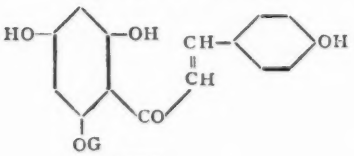


(XIX) R = H or CH_3

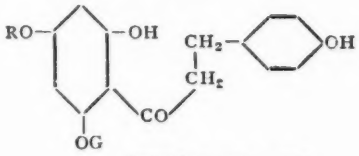
G = Sugar



(XX) R = H or OH



(XXI)



(XXII) R = H or CH_3

hydroxyls in the 2- and 6-positions have little stability and would immediately change into flavanones in which the 5-hydroxyl would become unreactive. Hence the sugar group should have entered in some as yet undetermined earlier stage. From the flavanone-5-glycoside to the flavone-5-glycoside is the next step involving oxidation or dehydrogenation. Zemplen and Meister[18] have been able to convert salipurposide (XIX, R = H) into the 5-glucoside of apigenin (XX, R = H). Hence in regard to the 5-glycosides also the ideas of glycoside formation at an earlier stage and sequential evolution have to be applied.

Summary

The sap-soluble pigments of plants consist of anthocyanins and a number of related groups of anthoxanthins. Any comprehensive theory of biogenesis should embrace all these groups. The theories of sequential and parallel origin are discussed. Based on chemical considerations with reference to certain methyl ethers and glycosides of anthoxanthins it is concluded that sequential origin should be recognised as playing a definite part though parallel evolution may be the major factor. Further, glycoside and ether formation may not be the last stages in evolution in all cases.

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THE INFLUENCE OF OPTICAL ACTIVITY ON LIGHT SCATTERING IN CRYSTALS

Part II. Sodium Chlorate

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1. Introduction

In a paper which appeared in these *Proceedings* (and which will be referred to as Part I), the author (Chandrasekharan, 1948) indicated for the first time that the optical activity of quartz could be successfully made use of for verifying the selection rules of Raman lines for polarised light traversing the crystal along the optic axis. The incident light vector, as it traverses the crystal, becomes alternately parallel and perpendicular to the plane of scattering. In the spectrogram of the light scattered in the transverse direction, both the Brillouin components and the Raman lines exhibit a banded structure. From the nature of the bands, it is possible to distinguish between Raman lines coming under symmetric class and those coming under degenerate class. These investigations have now been extended to the case of sodium chlorate crystal and the results are presented here.

In the case of optically active cubic crystals like sodium chlorate, the rotatory power is the same in all directions and is not masked by birefringence. Therefore, unlike in the case of quartz, the selection rules for the Raman lines of sodium chlorate which have already been worked out by Couture and Mathieu (1948) could be verified for more than one orientation of the crystal with reference to the directions of incidence and of observation. However, the smaller rotatory power of sodium chlorate which is nearly a tenth of that of quartz for λ 2537 would necessitate the use of a larger crystal. Besides, the Raman spectrum of sodium chlorate exhibits a few closely spaced doublets. In view of this, a spectrograph having a higher dispersion than the one used for studying quartz had to be employed.

2. Theoretical Considerations

Before describing the experimental results, it is considered desirable to describe briefly the selection rules for Raman lines in cubic crystals. According to the theory of the Raman effect, there are three classes of oscillations

possible which are usually designated by A—(totally symmetric), E—(symmetric with respect to the three 2-fold axes and doubly degenerate with respect to the four 3-fold axes of symmetry) and F—(triply degenerate with respect to the three 2-fold axes). Let us consider the case of transverse scattering. The intensity and the state of polarisation of the Raman lines belonging to Class A should remain unaffected for different orientations of the crystal since the tensor associated with each oscillation has spherical symmetry. In the case of degenerate oscillations coming under Classes E and F, on the other hand, the intensity and the state of polarisation should vary with orientation. For seven important settings of the crystal, the relative intensities as obtained theoretically are given in Table I. The method of evaluation is given in the paper by Couture and Mathieu (1948).

TABLE I

Setting	Incident light along	Scattered light along	Symmetry Class	Intensity of scattering in the transverse direction when the incident electric vector is		ρ'_u	Total intensity	Nature of banding
				$\perp r$ to plane of scattering	$\parallel$ to plane of scattering			
All			A	a	0	0	a	normal perfect
1	[100] "	[010] "	E F	$4e$ f	0 $2f$	0 2	$4e$ $3f$	normal perfect reverse imperfect
2*a*	[100] "	[011] "	E F	e $2f$	$3e$ f	3 1/2	$4e$ $3f$	reverse imperfect normal imperfect
2*b*	[011] "	[100] "	E F	$4e$ f	0 $2f$	0 2	$4e$ $3f$	normal perfect reverse imperfect
2*c*	[011] "	[01$\bar{1}$] "	E F	$4e$ f	$3e$ f	3/4 1	$7e$ $2f$	normal imperfect —
3*a*	[111] "	.. ..	E F	$3e$ $3/4f$	$3e$ f	1 4/3	$6e$ $7/3f$	— normal imperfect
3*b*	.. ..	[111] "	E F	$2e$ $5/3f$	$4e$ $2/3f$	2 2/5	$6e$ $7/3f$	reverse imperfect normal imperfect
3*c*	Plane of scattering (111)		E F	$2e$ $5/3f$	$3e$ f	$3/^2$ $3/^5$	$5e$ $8/3f$	reverse imperfect normal imperfect

The intensities of the Raman lines belonging to each class for incident unpolarised light are given in column 8. The intensities of the Raman lines for incident light polarised with electric vector perpendicular and parallel to the plane of scattering are given in columns 5 and 6 respectively. a, e and f are arbitrary quantities. ρ_u' represents the ratio of the intensity of any Raman line for incident light polarised with the electric vector parallel

to the plane of scattering to that of the same Raman line for incident polarised light with electric vector perpendicular to the plane of scattering, *i.e.*, the ratio of the value given in column 6 to that given in column 5. The values of ρ_u' are entered in column 7. The last column describes the appearance of the Raman lines coming under the different classes and for different settings when a beam of monochromatic light is passed through the crystal and the entire track inside the crystal is focussed on to and parallel to the slit of a spectrograph. The Raman lines, in general, exhibit fluctuations of intensity or banding throughout the length of the track. The banding is defined as "normal" when the intensity of scattering is maximum for incident electric vector perpendicular to the plane of scattering and minimum when the incident electric vector is parallel to it. If the reverse is true, the banding is termed as "reverse". Normal and reverse bandings are completely out of phase. Perfect banding is one in which the minimum is of zero intensity, while imperfect banding corresponds to the case when the minimum has a finite intensity.

In order to assign the Raman lines to the three different classes, it is sufficient if the experiment is carried out for two orientations of the sodium chlorate crystal corresponding to settings 1 and 2 (*a*). In the former setting, A and E lines behave in the same way, while F lines behave differently and consequently can be distinguished. In the latter setting, A and F lines behave nearly in the same way, while E lines exhibit reverse and imperfect banding and can therefore be identified. In the experiment to be described in the next section, only these two settings have been investigated.

3. Experimental Details

The specimen of sodium chlorate used in the present study was a synthetic crystal with well-developed cubic faces kindly presented by Dr. F. W. Mason of the Bell Telephone Laboratories, New Jersey. It had the following dimensions: 5·7 cm. × 5 cm. × 4·2 cm. Although there were some inclusions in the centre of the specimen, the portions near the edges were nearly free from flaws and defects of any kind. One of the edges was ground and polished normal to the dodecahedral direction for studying setting 2 (*a*) described in Table I.

The resonance radiation from a specially designed quartz mercury arc after polarisation with the aid of a nicol was focussed on the crystal in a vertical direction. The vertical track of the beam inside the specimen was focussed on the slit of a medium quartz spectrograph. As the condensing lens was not achromatic, its position was adjusted by trial to give the best focus in the region between λ 2537 and λ 2600. Exposures of the order of five days

had to be given. A mercury vapour filter was kept in the path of the scattered light as usual to absorb the resonance radiation. This enabled the Brillouin components due to the exciting radiation to be recorded on a clear background.

4. Results and Discussion

Figs. 1 (*a*) and 1 (*b*) in Plate (XVIII) represent the spectrograms obtained for the two different settings of the crystal with reference to the directions of incidence and observation. The banding for different lines is clearly visible in the photographs. Due to the presence of parasitic illumination, the mercury lines recorded do not exhibit as perfect a banding as the Raman lines. The length of the crystal is 5·7 cm. and nearly five bands were visible. In the figure reproduced in the Plate, only two bands are shown. The length of the bands was 11·9 mm. This agrees well with the value of 12·1 mm. calculated from the known rotatory power of sodium chlorate for λ 2537. As is to to be expected, the band width for the exciting line (λ 2537) is the same as that for the different Raman lines.

The Raman lines are marked in the figures. The Brillouin components exhibit perfect and normal banding. See Fig. 1 (*a*). For the second setting, the filtering was not very efficient. The Brillouin components are perfectly polarised irrespective of the orientation of the crystal. Unlike in the case of quartz, these components appear to be less intense than the symmetric oscillation (936) of sodium chlorate.

Comparing the behaviour of the individual Raman lines in the two settings investigated with that to be expected theoretically (Table I), the 15 Raman lines have been assigned as follows: 70 (E), 83 (F), 103 (F), 123 (F), 131 (A), 179 (E), 480 (E), 487 (F), 627 (A + F), 933 (F), 936 (A), 959 (E), 966 (F), 984 (F), 1026 (?). The author's assignments except for the 131 line are in general agreement with the conclusions arrived at by Couture and Mathieu (1948) from a study of the polarisation of the Raman lines in the usual way. The line 131 cm.$^{-1}$ has been classified by them as belonging to Class E. The fact that this line exhibits normal banding for the two settings (Fig. 1 *a* and 1 *b*) indicates clearly that it belongs to Class A. In place of the two lattice lines 83 (F) and 103 (F) cm.$^{-1}$ Couture and Mathieu reported the appearance of a single line at 92·5 cm.$^{-1}$ (F ?).

When a closely spaced doublet is formed of an E–F or A–F combination the resulting group for setting No. 1 shows a "zig-zag" course. This is because one component exhibits minimum intensity, when the second component has maximum intensity. See the doublets 123–31, 482–87 and 933–36 in Fig. 1 (*a*). Contrary to theoretical expectation, *the line* 936

belonging to Class A does not exhibit perfect banding, i.e., the depolarisation factor ρ_u' is not equal to zero and its value varies with orientation.

In agreement with the observation of Couture and Mathieu, the 1026 cm.$^{-1}$ line cannot be classified properly. Its origin itself has not been satisfactorily explained till now.

The author wishes to express his sincere thanks to Professor R. S. Krishnan for his constant encouragement and interest during the progress of the work. He also thanks Dr. F. W. Mason for kindly presenting the specimen of sodium chlorate crystal.

Summary

As in the case of quartz (Chandrasekharan, 1948), using the property of optical activity, the selection rules for Raman lines of sodium chlorate have been experimentally verified using λ 2537 excitation for two different orientations of the crystal. Its 15 Raman lines have been classified as follows into the various symmetry classes possible for a cubic crystal:— 70 (E), 83 (F), 103 (F), 123 (F), 131 (A), 179 (E), 482 (E), 487 (F), 627 (A+F), 933 (F), 936 (A), 959 (E), 966 (F), 984 (F), 1026 (−). The results agree with earlier ones of Couture and Mathieu (1948) except for the Raman line 131 cm.$^{-1}$ which they classify as belonging to Class E.

The Brillouin components are well polarised and weaker than the symmetric Raman line 936 cm.$^{-1}$

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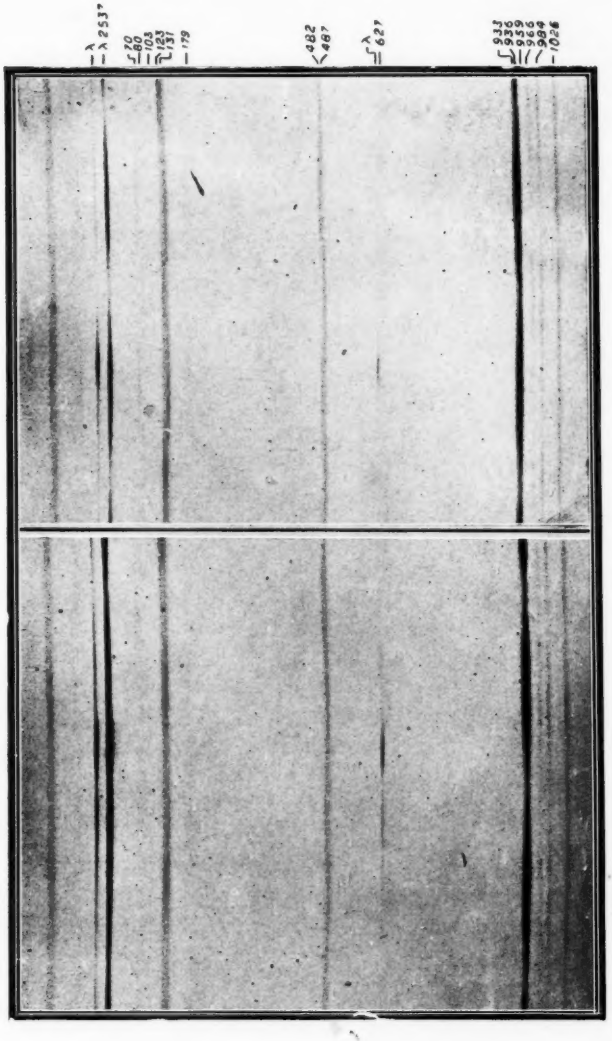

FIG. 1. Raman spectrum of sodium chlorate for two different orientations.
(*a*) Incident along [100]; Scattered along [010]
(*b*) Incident along [100]; Scattered along [011]

THERMAL SCATTERING OF LIGHT IN CRYSTALS

Part II. Diamond

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1. Introduction

As is well known, Brillouin (1922) put forward the view that a crystalline medium might be regarded as a continuum and that the diffusion of light by it arises from the coherent "reflection" of the light waves by sound waves of thermal origin traversing it in all directions. Consequently, the scattered spectrum should reveal Doppler-shifted components with frequency shifts from that of the incident monochromatic light of frequency ν, being given by

$$\Delta\nu = \pm 2\nu \frac{v}{c} \mu \sin \frac{\theta}{2}, \tag{1}$$

where v is the velocity of sound in the medium, μ its refractive index, c the velocity of light in vacuum and θ the angle of scattering. As there are one longitudinal or compressional and two transverse or equivoluminal waves in any particular direction travelling with different velocities, one might expect under favourable conditions to get six Brillouin components in the light scattered by any crystal. In Part I of the series (R. S. Krishnan and V. Chandrasekharan, 1950), the investigations on the fine structure of the thermal scattering of light in quartz using the λ 2536·5 mercury resonance radiation and a three-metre quartz spectrograph in combination with a mercury vapour filter to absorb the unmodified radiation from the scattered light, have been reported. The scattered spectrum in the case of quartz exhibits only one pair of Brillouin components due to the longitudinal sound waves in the medium. The dependence of the frequency shifts on the orientation of the crystal with reference to the directions of incidence and of scattering has been quantitatively verified for seven different settings of the crystal.

In the case of diamond, on account of the exceptionally large velocity of sound waves in it and its high refractive index, the Doppler-shifted components have been recorded by R. S. Krishnan (1947) using a medium quartz

spectrograph. With the help of the larger E1 spectrograph, two pairs of Brillouin components have been recorded by him, the outer arising from the longitudinal sound waves in diamond and the inner brighter ones due to the transverse sound waves. It was considered desirable to re-investigate the case of diamond using the three-metre quartz spectrograph. This has been carried out by the author for four different orientations of the diamond with reference to the directions of incidence and of observation.

2. Experimental Details

The two specimens of diamond, kindly lent by Sir C. V. Raman and used in the present investigation were the same as those studied by R. S. Krishnan. One of them, namely, NC 60, was in the form of a rectangular plate ($10 \times 6 \times 1 \cdot 3$ mm.) with faces and edges well polished. The length, breadth and thickness of the diamond were respectively parallel to [011], [111] and [211]. The specimen was well suited for studying the effect of orientation. However, as it was slightly yellowish in colour, its transparency to $\lambda\,2536 \cdot 5$ radiation was not great. The other specimen NC 174 had curved edges and therefore, was not well suited for the study.

Diamond NC 60 was held in a special brass holder with one of its faces vertical and facing a vertical water-cooled quartz mercury arc of special design. The light scattered in the transverse horizontal direction and emerging out of another face was focussed on the slit of a Hilger three-metre spectrograph. It had a dispersion of $14 \cdot 1$ cm.$^{-1}$ per millimetre in the $\lambda\,2536 \cdot 5$ region. Because of its large dispersion and the high resolving power of 300,000, the displaced components were recorded so well separated from one another that the shifts could be estimated even with a glass scale.

The light scattered by a crystal is generally accompanied by parasitic light both due to flaws in the specimen as well as from reflections from its surface, especially so in the case of small specimens. Hence a filter of mercury vapour kept in the path of the scattered light suppressed the unmodified resonance radiation from the scattered light and thus enabled the Brillouin components to be recorded on a clear background. Because of the effective water-cooling, magnet control and continuous evacuation, the arc emitted the resonance radiation ($\lambda\,2536 \cdot 5$) with great intensity. Even so, exposures of the order of two days had to be given to record both pairs of Brillouin components clearly, using a slit-width of $0 \cdot 02$ mm.

With the help of a medium quartz spectrograph, the Brillouin components arising from the transverse waves were recorded for backward scattering along [111]. However, due to the small depth of illumination, the

backwardly scattered light was very feeble and even with exposures of the order of five days, the recorded spectrum was too faint to be reproduced.

3. Results

A typical photograph showing the Brillouin components and the first order Raman spectrum is reproduced in Fig. 1 (*a*) (same size). It is seen that the parasitic light is reduced to a minimum *so that* λ 2534·8 *Hg line is recorded with an intensity less than that of the Brillouin components due to the transverse waves,* while the λ 2576·3 Hg line is not recorded. The absorption of the mercury vapour kept in the scattered path extends to a certain degree on either side of λ 2536·5, the absorption being greater on the longer wavelength side. However, in the case of diamond, on account of the large separation of even the Brillouin components due to transverse waves, the mercury vapour produces practically no asymmetry or reduction in intensity of the Brillouin components.

Figs. 1 (*d*), (*e*) and (*f*) in Plate (XIX) show the Brillouin components in transverse scattering for three different settings of diamond (enlarged 20 times in each case). They show clearly the dependence of the separation of the components on orientation. Fig. 1 (*b*) is an enlargement of the Doppler-shifted components in quartz for backward scattering, while Fig. 1 (*c*) shows the components both in quartz as well as in diamond for transverse scattering (photographed on the same plate). The Brillouin components in diamond are definitely broader than those in quartz. This is probably due to the large convergence of the incident light necessitated by the small dimensions of the crystal. The semi-angle of convergence amounts to at least 15° in the case of diamond. This could not be reduced further without undue increase in the time of exposure.

The frequency shifts of the Brillouin components for five different orientations studied have been measured, assuming that the separation between λ 2534·76 and λ 2536·52 is equal to 27·02 cm.$^{-1}$ (Burns, 1950) and entered in Table I along with the corresponding values of the shifts calculated using equation (1) and the known elastic constants. The values of the various constants used are $\mu = 2 \cdot 624$, $\rho = 3 \cdot 514$ gm. cm.$^{-2}$, $\nu = 39{,}412$ cm.$^{-1}$, $c_{11} = 95 \times 10^{11}$, $c_{12} = 39 \times 10^{11}$ and $c_{44} = 43 \times 10^{11}$ dynes/cm.^{2} (Bhagavantam and Bhimasenachar, 1946). The agreement between calculated and observed shifts is not very satisfactory. Both Krishnan's and the author's values are definitely higher than those calculated for the components due to transverse waves, while the author's measurements show a slightly smaller value for the longitudinal component.

In cases 1 and 2, the direction of incidence with reference to the orientation of the crystal was kept the same, while the light scattered transversely in opposite directions was recorded. The observed shifts of the Brillouin components are different for the two cases. This difference arises from the fact that the direction of the elastic wave responsible for light scattering is different in the two cases. Only, if either the direction of incidence or of observation coincides with either a two-fold or four-fold symmetry axis of the crystal or if there is a plane of reflection perpendicular to either, will the two cases be identical. The wave-normal of the elastic waves responsible for light scattering travels along the external bisector of the incident and scattered directions and hence, in case 1, it was approximately along [144] or about 10° from the [011] direction, while in case 2, it was along [811] or about 10° from the [100] direction. The separation of the longitudinal components from the transverse components is smaller in case 2 [Fig. 1 (ϵ)] than in case 1 [Fig. 1 (f)]. In cases 3 and 4, as the direction of the scattered light [011] is one of two-fold symmetry, these differences are absent. Hence the six possible settings of a parallelopiped with reference to the directions of incidence and observation reduce to only four for the diamond used. In case 4, as the light had to be incident along the breadth through one edge and the scattered light was taken out through another edge, the recorded spectrogram was too weak to be reproduced.

Along any given direction, there are three possible sound velocities. However, in most cases, the sound velocities for the two sets of transverse waves are nearly the same for diamond. The maximum difference is along the dodecahedral axis, the corresponding calculated separation of the Brillouin components arising from the two sets of transverse waves being 5·4 and 4·35 cm.$^{-1}$ Hence, in this case, two pairs of transverse components should have been separately recorded or if they are not seen clearly resolved, the observed transverse components should at least appear very broad. Case 1 in which the effective wave travels along a direction inclined only 10° to [011], corresponds nearly to the above case. But only one pair of Doppler components of normal width due to transverse waves was recorded. This is indeed surprising.

4. Intensity Measurements

By microphotometering the negatives and using the standard method of graded intensity marks, an estimate of the intensities of the longitudinal and transverse Brillouin components and of the 1332 cm.$^{-1}$ Raman line was made for the first three cases of Table I. The ratio of intensities of the transverse to the longitudinal Brillouin components is entered in the last

TABLE I*

No.	Fig. No.	Incident along	Scattered along	Scattering angle	Nature of Brillouin components	Shift observed in cm.$^{-1}$ Author's values	Krishnan's values in cm.$^{-1}$	Shift calculated cm.$^{-1}$	Ratio of intensities T.B.C./L.B.C.	Ratio of intensities Raman/B.C.
1	*f* & *a*	[2$\bar{1}$1]	[111]	90°	Longitudinal	8·56	..	8·66	2·3	12·0
		[2$\bar{1}$1]	[111]	90°	Transverse	5·63	..	5·39 4·38		
2	*e*	[2$\bar{1}$1]	[$\bar{1}\bar{1}\bar{1}$]	90°	Longitudinal	8·09	8·2	8·11	3·3	8
		[2$\bar{1}$1]	[$\bar{1}\bar{1}\bar{1}$]	90°	Transverse	5·88	6·7	5·36 5·29		
3	*d* & *c*	[2$\bar{1}$1]	[01$\bar{1}$]	90°	Longitudinal	8·50	9·0	8·68	1·8	7
		[2$\bar{1}$1]	[01$\bar{1}$]	90°	Transverse	5·58	5·5	5·02 4·78		
4		[111]	[01$\bar{1}$]	90°	Longitudinal	..	8·7	8·43	..	..
		[111]	[01$\bar{1}$]	90°	Transverse	5·59	5·6	5·12		
5		[111]	[$\bar{1}\bar{1}\bar{1}$]	180°	Longitudinal	..	..	12·47	..	..
		]111]	[$\bar{1}\bar{1}\bar{1}$]	180°	Transverse	7·0	..	6·69		

* T.B.C.=Transverse Brillouin component. L.B.C.=Longitudinal Brillouin component.

but one column of Table I. It is seen that the ratio is always greater than one and that it varies with the orientation of the crystal. The ratio of the intensity of the Raman line to the sum of the intensities of the two pairs of Brillouin components in different cases is entered in the last column of Table I. Unlike in quartz, for which the principal Raman line 466 cm.$^{-1}$ is weaker than the Brillouin components, the Raman line 1332 cm.$^{-1}$ of diamond is nearly seven to twelve times as intense as the sum of the intensities of the Brillouin components at room temperature.

In the estimation of the intensities, no correction has been made for the finite angle of convergence of the incident beam. Further, there were complications arising from the appreciable intensity of reflection of the incident light from the back surface of the crystal as a consequence of its high refractive index. At normal incidence the reflectivity of diamond for λ 2537 amounts to as much as 20%. Its effect has been neglected in the estimation of intensities.

According to Leontowitsch and Mandelstamm (1932), the light reflected or transversely scattered by sound waves of thermal origin in a medium is given by the formula.

$$I = \frac{\pi^2}{2\lambda^4} kT\mu^8 \left\{ \frac{2(p_{12}^2 + p_{44}^2)}{c_{11} + c_{12} + 2c_{44}} + \frac{p_{44}^2}{c_{44}} \right\}, \qquad (2)$$

where I is the intensity of the light scattered by 1 cm.^{3} of the substance for natural light of unity intensity, λ the wave-length, μ the refractive index, c_{ik} elastic constants, p_{ik} Pockel's elasto-optic constants and T the temperature of the scattering substance.

According to Hans Mueller's analysis (1938), the first term inside the double brackets in (2) is the contribution due to the longitudinal sound waves, while the second term is due to the transverse waves. The values of the elasto-optic constants as determined by Ramachandran (1950) recently are $p_{11} = -0{\cdot}31$, $p_{12} = 0{\cdot}09$, $p_{44} = -0{\cdot}12$. Using these corrected values, the intensities of the longitudinal and transverse Brillouin components are respectively $0{\cdot}23 \times 10^{-5}$ and $0{\cdot}37 \times 10^{-5}$. Thus the transverse components should be about 1·6 times as bright as the longitudinal components. This behaviour is due to the large value of p_{44} as compared to p_{12} unlike in many other crystals of cubic symmetry in which generally p_{44} is very much smaller than p_{12}. The observed values for the intensity ratio are nearly of the same order of magnitude as predicted by the theory.

However, the theory of Leontowitsch and Mandelstamm is valid only for a specific orientation of a cubic crystal, namely, when the directions of incidence and of observation coincide with the cubic axes. The intensity would be independent of orientation only in amorphous substances, which have spherical symmetry and for which a relation exists between p_{11}, and p_{12} and p_{44}, namely, $p_{11} - p_{12} - 2p_{44} = 0$ and a similar relation $c_{11} - c_{12} - 2c_{44} = 0$. In crystals belonging to the cubic class, the above relations are not satisfied and consequently, both the shift and intensity of the Brillouin components should vary with orientation, as is shown by the observed results in the case of diamond. The intensities of thermal scattering in cubic crystals for specific orientations have been worked out by the author and the results will be reported later.

The author is grateful to Professor R. S. Krishnan for his constant encouragement and suggestions and to Professor Sir C. V. Raman for the loan of the diamonds used in the investigation. I also wish to express my sincere thanks to the National Institute of Sciences for the award of the Junior Research Fellowship and to Dr. G. N. Ramachandran for helping me to determine the orientations of the diamond.

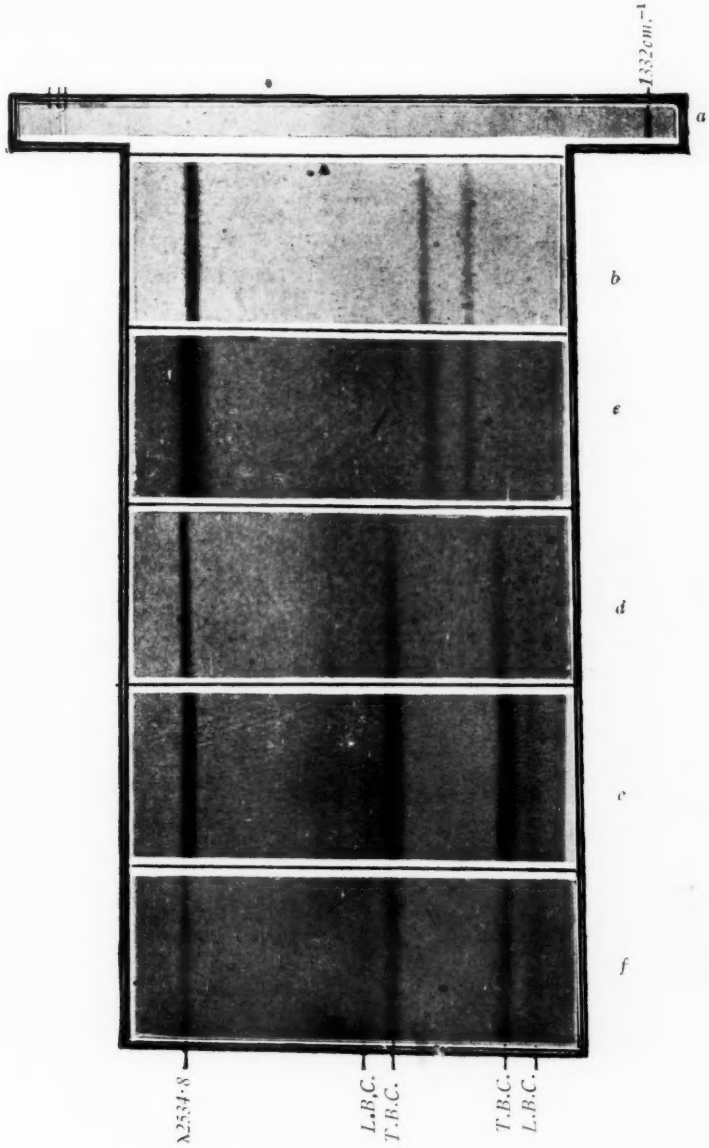

FIG. 1. Brillouin Components in Quartz and Diamond

5. Summary

The thermal scattering of light in diamond has been studied with the help of a three-metre quartz spectrograph using the λ 2536·5 mercury radiation as exciter. The scattered spectrum shows two pairs of Doppler-shifted components clearly resolved from each other, one pair due to the longitudinal sound waves and the other due to the two sets of transverse sound waves which have nearly the same velocity. The dependence of the frequency shifts on the orientation of the crystal with reference to the incident and observation directions has been verified for five settings. The observed shifts are not in very good agreement with the values calculated from the elastic constants, the transverse components having shifts *definitely* larger and the longitudinal components having shifts slightly smaller than the expected values. The interesting fact that the shifts of the Brillouin component are generally different for light scattered transversely in opposite directions, the direction of the incident light being kept the same, has been verified in two cases. The difference arises from the fact that the direction of propagation of the elastic waves responsible for light scattering is not necessarily the same in the two cases. The transverse components are found to be 1·5 to 3 times more intense than the longitudinal components, depending on the orientation of the crystal. The principal Raman line 1332 cm.$^{-1}$ is 7 to 12 times as intense as the sum of the intensities of the two pairs of Brillouin components.

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FLAVONOLS: DIRECT NEW SYNTHESIS OF 6-HYDROXY-FLAVONOLS

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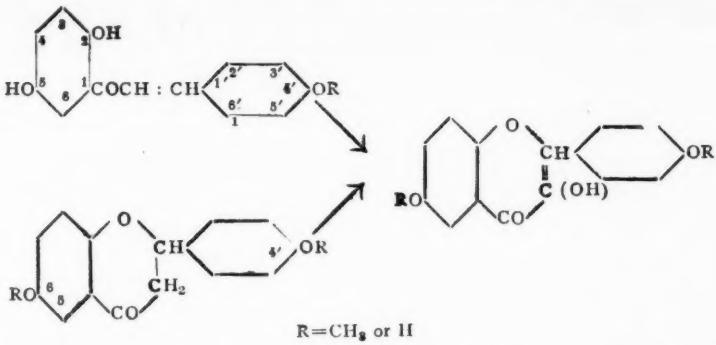
Several investigators have done a large amount of work on flavonols containing resorcinol and phloroglucinol nucleii. However, the flavonols containing quinol nucleus have not received so much attention. Kostanecki and coworkers[1] synthesised a number of 6-hydroxy-flavonols from the corresponding methoxy-flavanones by subjecting them to amyl-nitrite reaction, subsequent hydrolysis and demethylation.

Among the methods which have been described for the synthesis of hydroxy-flavonols, the oxidation of *O*-hydroxy-chalkones by means of alkaline hydrogen peroxide—Algar and Flynn[2] method has been successfully applied by several investigators notably by Oyamada,[3] Murakami and Irie.[4] However, Geissman and Fukushima[5] found that the chalkones derived from phloracetophenone dimethyl ether with anisaldehyde, benzaldehyde and veratraldehyde, etc., gave on Algar-Flynn oxidation predominantly the benzalcoumaranones instead of the expected flavonols. They attributed this abnormal behaviour to the presence of 6-methoxy group in the chalkone used.

Recently Anand, Iyer and Venkataraman[6] have found that the Algar-Flynn oxidation of *O*-hydroxy-chalkones to flavonols by means of alkaline hydrogen peroxide is applicable to chalkones with a hydroxyl group at 4′ irrespective of the presence of OMe at 6. Thus they have been able to synthesise rhamnazin[4]5-methyl ether from 2-hydroxy-4-6-dimethoxy-phenyl-4′-hydroxy-3′-methoxy-styryl-ketone in one step.

In continuation with our work on chalkones and flavanones derived from quinacetophenone[7] we have applied the Algar-Flynn oxidation for synthesis of 6-hydroxy-flavonols directly from the hydroxy-chalkones. The reaction was found to be smooth and no other products like benzal-coumaranones could be isolated. 6-Hydroxy-flavonols have now been made directly from 2:5-dihydroxy-, 2:5:2′-trihydroxy-, 2:5:4′-trihydroxy-chalkones as well as from 6:4′-dimethoxy- and 6:3′-dihydroxy-flavanones. They all agree with the compounds prepared by Kostanecki and his coworkers.



R=CH_3 or H

Thus it is obvious that the presence of OH or OCH_3 group in 5-position in the quinacetophenone nucleus as well as hydroxy group in the styryl part of the chalkone does not affect the normal course of the oxidation. It is interesting to point out that in all the cases the hydroxy-flavonols were obtained directly in good yield. The 6-hydroxy-flavonols described here dissolve in concentrated sulphuric acid with greenish yellow fluorescence and in alkali with greenish yellow colouration. With alcoholic ferric chloride, they give greenish red colour.

Experimental

6-Hydroxy-flavonol

To an ice-cold red solution of 2: 5-dihydroxy chalkone (1·0 g.) in sodium hydroxide (30 c.c.: 5 per cent.) and methyl alcohol (20 c.c.) was gradually added hydrogen peroxide (8 c.c.: 18 per cent.) with shaking and cooling in ice-bath. The mixture was kept in ice-bath for 2 hours and then left overnight at room temperature. The colour of the solution changed from dark red to pale yellow. It was mixed with ice (200 g.) and acidified with dilute sulphuric acid (2 N). A pale yellow solid separated which was crystallised from dilute alcohol, pale yellow needles, m.p. 234°. Yield = 0·5 g. (approximately 50%). Kostanecki and Lampe[1] give the same melting point.

The acetyl derivative prepared by sodium acetate-acetic anhydride method, crystallised from dilute alcohol, colourless lustrous needles, m.p. 195°. Kostanecki and Lampe[1] record the same melting point (Found: C, 67·3; H, 4·0. Calculated for $C_{19}H_{14}O_6$: C, 67·45; H, 4·1 per cent.)

6: 2′-Dihydroxy-flavonol

2: 5: 2′-Trihydroxy-chalkone (1 g.) was subjected to hydrogen peroxide (5 c.c.: 18 per cent.) oxidation as in the previous case and the pale yellow solid obtained on similar treatment as before was crystallised from dilute

alcohol, long colourless needles, m.p. 243°. Yield = 0·45 g. Kostanecki and Katschalowsky[1] give the same melting point.

The *methyl ether*: 6:2′-Dihydroxy flavonol (0·5 g.) in methyl alcohol (20 c.c.) was methylated by dimethyl sulphate (4 c.c.) and sodium hydroxide (20 c.c.: 8 per cent.). The mixture was heated on water-bath for 2 hours when the methyl alcohol evaporated and an insoluble brownish yellow solid separated. It was collected and crystallised from methyl alcohol, yellow prismatic needles, m.p. 187°. Kostanecki and Katschalowsky[1] give the same melting point (Found: C, 68·2; H, 4·6. Calculated for $C_{17}H_{14}O_5$: C, 68·4; H, 4·7 per cent.).

6:4′-*Dihydroxy-flavonol*

2:5:4′-Trihydroxy-chalkone (1 g.) was oxidised as in the previous cases by means of hydrogen peroxide (8 c.c.: 18 per cent.). The pale yellow solid isolated as usual was crystallised from methyl alcohol, pale yellow short needles. It did not melt upto 300°. Yield = 0·3 g. (Found: C, 66·5; H, 3·6. Calculated for $C_{15}H_{10}O_5$: C, 66·7; H, 3·7 per cent.).

The acetyl derivative prepared as before, crystallised from dilute alcohol, colourless flat needles, m.p. 169°. Kostanecki and Stoppani[1] give the same melting point (Found: C, 63·4; H, 4·1. Calculated for $C_{21}H_{16}O_8$: C, 63·6; H, 4·0 per cent.).

6:3′-*Dihydroxy-flavonol*

6:3′-Dihydroxy-flavanone was treated with hydrogen peroxide (4 c.c.: 18 per cent.) in ice-bath and the flavonol isolated as before. It crystallised from alcohol, colourless needles, m.p. 300°. Yield = 0·5 g. Kostanecki and Ottmann[1] record the same melting point.

The acetyl derivative was prepared as before, crystallised from dilute alcohol, colourless needles, m.p. 126°. Kostanecki and Ottmann[1] record the same melting point (Found: C, 63·5; H, 4·2. Calculated for $C_{21}H_{16}O_8$: C, 53·6; H, 4·0 per cent.).

6:4′-*Dimethoxy-flavonol*

6:4′-Dimethoxy-flavanone (0·5 g.) was oxidised as before by using hydrogen peroxide (20 c.c.: 8 per cent.) and sodium hydroxide (10 c.c.: 16 per cent.) in methyl alcohol or acetone (50 c.c.) in the usual manner keeping the reaction mixture in ice-bath for 3 hours and then for two days at room temperature. The flavonol was isolated as before and crystallised from methyl alcohol, pale yellow needles, m.p. 185°. Yield = 0·4 g. Kostanecki and Stoppani[1] give the same melting point.

The acetyl derivative prepared as before, crystallised from dilute alcohol, colourless needles, m.p. 131–32° (Found: C, 67·0; H, 4·6. $C_{19}H_{16}O_6$ requires: C, 67·1; H, 4·7 per cent.).

Summary

The synthesis of 6-hydroxy-flavonols has been effected by the Algar and Flynn oxidation of 2:5-dihydroxy-, 2:5:2′-trihydroxy-, 2:5:4′-trihydroxy-chalkones and 6:3′-dihydroxy- and 6:4′-dimethoxy-flavanones by means of alkaline hydrogen peroxide. The flavonols obtained have been characterised by preparing their acetyl or methoxy derivatives. It is interesting to note that free hydroxyl group in either nucleus of the chalkone molecule does not lead to complications during the oxidation, the flavonols being obtained in good yield.

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A NEW SYNTHESIS OF THIOPHENES AND THIAPYRANS[1]

Part I. A New Synthesis of Thionaphthene, Its Scope and Limitations

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(Communicated by Dr. K. Venkataraman, F.A.SC.)

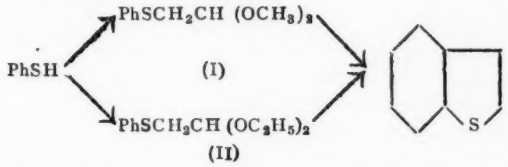
With the discovery of penicillin, α- and β-biotins, increased attention is being devoted in recent years to the synthesis of heterocyclic compounds where sulphur forms a part of the ring system. The close similarity in the physical and chemical properties of benzene and thiophene and their analogous derivatives, led Erlenmeyer to suggest the equivalence, "isosterism", of a divalent sulphur atom to the group,—CH = CH —("pseudo-atom"), such compounds being termed "isosters".[2] A number of sulphur isosters of physiologically active compounds have been reported, the comparative activity of the two series of compounds have been studied, and in many cases it has been found that the sulphur isosters showed similar physiological action.

In connection with the preparation of sulphur isosters of carcinogenic hydrocarbons,[1] the syntheses of thionaphthene and its higher polycyclic derivatives were studied. The methods available for the synthesis of thionaphthene are: (1) condensation of *o*-mercaptobenzaldehyde with chloroacetic acid in alkaline solution followed by the decarboxylation of the resulting thionaphthene-2-carboxylic acid,[3] (2) cyclization of *o*-mercaptocinnamic acid,[4] (3) cyclization of *o*-mercaptostyrene,[5] (4) reaction of styrene with hydrogen sulphide at 625° in presence of ferrous sulphide-aluminium oxide catalysts,[6] (5) reaction of ethylbenzene with hydrogen sulphide at 575° using chromia on alumina catalyst[7] and (6) the reduction of thioindoxyl with zinc and acetic acid.[8] The last method has also been widely used in the syntheses of substituted thionaphthenes and higher polycyclic derivatives of thionaphthene, but it suffers from two main disadvantages: the instability of thioindoxyls due to air oxidation and the low yields in their conversion to thionaphthenes.[8, 9]

Attempts have been made to synthesise thionaphthenes by the ring-closure of α-phenylmercapto ketones and aldehydes in analogy with the

syntheses of benzofurans. Thus Delisle[10] made unsuccessful attempts to cyclize phenyl acetonyl sulphide. Autenrieth[11] likewise failed to cyclize phenyl ω-diethoxyethyl sulphide (II) by treatment with acidic reagents. The synthesis of 6-hydroxy-3-phenylthionaphthene by cyclization of 3-hydroxyphenyl phenacyl sulphide with sulphuric acid, is the only example of cyclization in the thionaphthene series.[12] The failure to synthesise thionaphthenes has been attributed by Bradsher[13] to the instability of the phenyl sulphydryl ketones and aldehydes, as also to the low order of *ortho* activation by the thioether group. Werner[14] has however recently synthesised a series of thionaphthenes with substitutents in two and/or three positions by cyclization of α-arylmercaptoketones by treatment with a mixture of zinc chloride and phosphorus pentoxide.

Ring-closure of phenyl ω-dimethoxyethyl sulphide (I) by treatment with acidic dehydrating agents, such as sulphuric acid of varying strengths; sulphuric acid in acetic acid or glycerine; phosphorus oxychloride; anhydrous aluminium chloride, stannic chloride and phosphorus oxychloride in dry benzene; phosphorus pentoxide and phosphoric acid sp.gr. 1·75, was studied. It is found that cyclization of (I) and (II) with a mixture of phosphorus pentoxide and phosphoric acid gives thionaphthene in an optimum yield of 37 and 32 per cent. respectively.



The synthesis of thionaphthene has been extended to mono-substituted thionaphthenes containing substituents such as, methyl, chloro, hydroxy, alkoxy, etc. Starting from naphthalene mono and dithiols, polycyclic compounds containing naphthalene and thiophene or thiapyran ring systems have also been prepared. Phenanthrene monothiols led to more complex sulphur-containing polycyclic compounds. The work will be reported in subsequent communications.

The new synthesis, in general, consists in the reaction of aryl thiols Ar $(SH)_n$ with bromoacetaldehyde dimethyl acetal followed by the cyclization of aryl ω-dimethoxyethyl sulphides (S-arylthioglycolicaldehyde dimethyl acetals) Ar $[SCH_2CH(OMe)_2]_n$ to give sulphur-containing heterocyclic compounds. The only requisites appear to be aryl thiols with free *o*- or *peri* positions to the thiol groups to enable the cyclization of the thioglycolic aldehyde dimethyl acetal side chain $[SCH_2CH(OMe)_2]_n$.

The scope of the synthesis is indicated by the variety of compounds which have so far been synthesised by this method. Unlike the syntheses of higher polycyclic thiophene derivatives starting from a performed thiophene ring system, in the present synthesis a five- or a six-membered sulphur-containing ring is built up on an aryl residue. The scope of the synthesis in the preparation of monosubstituted thionaphthenes appears to be limited to 5-, 6- and 7-substituted derivatives. *o*- and *p*-Substituted aryl thiols lead to 7- and 5-substituted thionaphthenes respectively. In the case of *m*-substituted aryl thiols the cyclization of the intermediate thioglycolic-aldehyde dimethyl acetals may yield 4- or 6-substituted thionaphthenes depending on the direction of cyclization. The formation of 4-substituted thionaphthenes is, however, probably minimised or precluded because of steric hindrance. Mono-substituted thionaphthenes prepared in the present work from *m*-substituted aryl thiols have, therefore, been constituted as 6-substituted derivatives, although the formation of the 4-substituted isomers in low yields cannot be ruled out. It may be noted that among the monosubstituted thionaphthenes, with the exception of 2- and 3-substituted thionaphthenes, only a few thionaphthenes with substituents in the benzene half of the molecule are known. These are now readily synthesised by the new method.

Another limitation of the synthesis at present appears to be the drastic treatment with phosphorus pentoxide and phosphoric acid involved in the cyclization of the intermediate sulphides, which may preclude its application to compounds which are unstable under these conditions. Further experiments to effect cyclization of the intermediate sulphides such as (I) under milder conditions have been undertaken.

Experimental

(Microanalyses are by Drs. Weiler and Strauss, Oxford, Melting points are uncorrected.)

General method for the preparation and characterization of aryl ω-dimethoxyethyl sulphides

An absolute alcoholic solution of the aryl thiol (1 mol.) was added to a solution of sodium ethoxide (1 mol.) in absolute alcohol followed by the addition of sodium iodide (about 0·1 mol.) and bromoacetaldehyde dimethyl acetal[15] (1 mol.). The mixture was heated under reflux for 2–6 hours and the excess of alcohol was removed by distillation. The residue was diluted with water and the crude sulphide was isolated by means of ether and purified by distillation under reduced pressure. The sulphide was characterised by preparation of the 2:4-dinitrophenylhydrazone of the parent *S*-arylthioglycolic-aldehyde by addition to an alcoholic solution of 2:4-dinitro-

phenylhydrazine containing a few drops of concentrated sulphuric acid and warming the mixture.

General method for the ring-closure of liquid sulphides

The sulphides (5 g.) were added gradually through a separating funnel to a mixture of phosphorus pentoxide (20–25 g.) and syrupy phosphoric acid, sp.gr. 1·75 (12–15 c.c.), kept in a distilling flask and previously heated under reduced pressure to a temperature near the boiling point of the sulphides. It was necessary to add the sulphides below the surface of the phosphorus pentoxide-phosphoric acid mixture to get an optimum yield of the cyclized product. After each addition a vigorous reaction set in with simultaneous distillation of the crude cyclized product usually in the form of a colourless liquid. The distillate was treated with excess of saturated alcoholic solution of picric acid, the picrate obtained was decomposed with alkali and the cyclized product was isolated by means of ether or by steam distillation. An alternative method for the decomposition of the picrate was to pass a benzene solution of the picrate through a column of activated alumina.

Phenyl ω-dimethoxyethyl sulphide (*I*)

A mixture of thiophenol[16] (35·1 g.), sodium (7·4 g.), sodium iodide (4·8 g.), bromoacetaldehyde dimethyl acetal (54·1 g.) and absolute alcohol (170 c.c.) was boiled for 3 hours. The crude sulphide (51·4 g.) gave a colourless liquid after distillation, b.p. 130–32°/6 mm. (47·8 g.; yield 76%). It was further purified by redistillation and finally collected at b.p. 170–75° (bath temp.)/6 mm. (Found: C, 60·1; H, 7·0; S, 16·0. $C_{10}H_{14}O_2S$ requires C, 60·6; H, 7·1; S, 16·2%). 2:4-*Dinitrophenylhydrazone* after crystallization from alcohol gave lustrous yellow-orange needles, m.p. 102·5–103·5° (Found: N, 17·3. $C_{14}H_{12}N_4O_4S$ requires N, 16·9%).

Ring-closure of the sulphide (*I*)

The different attempts to cyclize (I) are summarised in Table I. Only those experiments where thionaphthene was obtained as shown by the formation of the picrate, m.p. 150°, have been included in the table. The experiment (No. 8) where an optimum yield of thionaphthene (37%) was obtained is described below.

The sulphide (15 g.) was added to a mixture of phosphorus pentoxide (60 g.) and phosphoric acid (36 c.c.) at 160°/5 mm. The colourless distillate (7·25 g.) was treated with a saturated alcoholic solution of picric acid (45 g.). The picrate was decomposed with 5% sodium hydroxide solution and thionaphthene was isolated by means of ether. Removal of ether gave thionaphthene in the form of colourless flakes, m.p. 30–32° (3·94 g.; yield 37%).

The picrate after recrystallization from alcohol gave long yellow needles, m.p. 151° (Found: S, 9·0. Calc, for $C_{14}H_9N_3O_7S$: S, 8·8%).

Phenyl ω-diethoxyethyl sulphide (II)

Sodium (2·3 g.), thiophenol (10·3 c.c.), sodium iodide (1·5 g.), chloro acetaldehyde diethyl acetal (15·3 g.) and absolute alcohol (50 c.c.) were boiled for 2 hours. The sulphide gave a colourless liquid after distillation b.p. 120–30°/2 mm. (Autenrieth,[10] gives b.p. 273°) and gave a 2:4-dinitrophenylhydrazone identical with the hydroazone prepared from (I).

Ring-closure of the sulphide (II)

The sulphide (2·5 g.) when treated with a mixture of phosphorus pentoxide (10 g.) and phosphoric acid (6 c.c.) at 160°/2 mm., gave thionaphthene (0·48 g., yield 32%) which was isolated through the picrate.

TABLE I

Experiment No.	Amount of (I) g.	P_2O_5 g.	H_3PO_4 sp.gr. 1·75, c.c.	Yield of crude thionaphthene g.	Yield of pure thionaphthene isolated through picrate		Procedure
					g.	%	
1	2·5	10	6	..	0·1	..	(I) Added to P_2O_5–H_3PO_4 mixture at 140-50°. Thionaphthene isolated by steam distillation
2	2·5	20	12	..	0·09	..	As above. Mixture heated for 15 minutes
3	2·5	5	..	0·14	..	..	Mixture of (I) and P_2O_5 heated in vacuum. Vigorous reaction takes place at 110° (bath temp.), and a pale yellow oil, b.p. 60°/5 mm., distills over
4	2·5	7·5	..	0·14	..	..	Mixture of (I) and P_2O_5 distilled at atm. pressure
5	3	7·5	..	0·7	..	..	(I) Added dropwise to P_2O_5 kept at 140-50°/5 mm. Colourless liquid (0·7 g.) distills over
6	2	5	3	0·63	0·135	10	(I) Added to P_2O_5–H_3PO_4 mixture at 140-50°/10 mm. during 16 min., mixture heated for 15 min. Crude product was purified through picrate
7	3·2	13·2	8	0·805	0·28	13	(I) Added to P_2O_5–H_3PO_4 mixtr. during 5 min. at 150–60/4 mm. mixture then heated to 200°. The crude product was purified through picrate
8	15	60	36	7·25 (72·5%)	3·94	37	(I) Added below the surface of P_2O_5–H_3PO_4

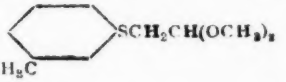
ERRATA

Proc. Ind. Acad. Sci., Vol. XXXII, Sec. A, No. 6

Part I. Page 394, In line 8 from top, the word "hydroazone" should be replaced by the word "hydrazone".

Part II. Page 396, 1st para, line 8, from top *for* 'thionaphthene.' *read* 'thionaphthenes.'

Page 397, In formula (III), shift CH_3 group to the left, so that it is *m*- to side chain. The correct representation is



Page 400, In line 18 from top, insert a '/' between "160–80°" and "110 mm." The correct representation is "160–80°/110 mm."

Summary

Cyclization of phenyl ω-dimethoxyethyl sulphide (I) under different conditions was studied and an optimum yield of 37% of thionaphthene was obtained by treatment with a mixture of phosphorus pentoxide and phosphoric acid under closely defined conditions. Phenyl ω-diethoxyethyl sulphide (II) also gave thionaphthene in 32% yield under similar conditions.

The new synthesis of thionaphthene, which has been extended to substituted thionaphthenes and to other thiophenes and thiapyrans reported in subsequent communications consists in the cyclization of aryl ω-dimethoxyethyl sulphides Ar $[SCH_2CH(OMe)_2]_n$. The scope and limitations of the new synthesis are discussed.

I am indebted to Sir Robert Robinson, P.R.S., O.M., for his kind interest in the work and a part of the work described in the three forthcoming communications, which was carried out in Dyson Perrins Laboratory, Oxford, during 1944-46.

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A NEW SYNTHESIS OF THIOPHENES AND THIAPYRANS

Part II. Monomethylthionaphthenes and Monochlorothionaphthenes

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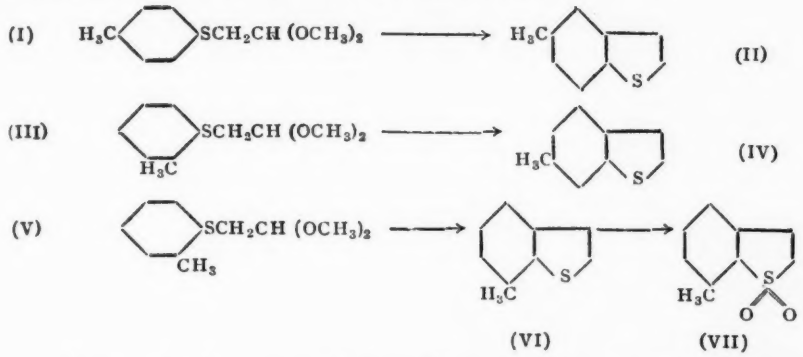
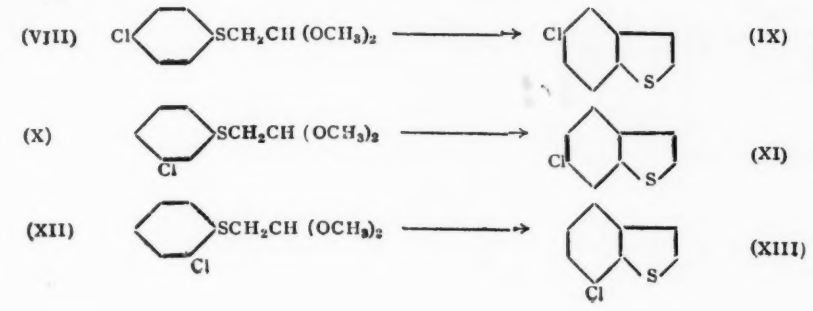
Of the six possible monomethylthionaphthenes, 2-, 3-, 5- and 6-methylthionaphthenes are known. 2-Methylthionaphthene[1] has been prepared by the reduction of 3-hydroxy-2-methylthionaphthene; the latter is obtained from α-(*o*-carboxyphenylmercapto)-propionic acid. 3-Methylthionaphthene has been synthesized recently by Werner[2] by the cyclization of phenyl acetonyl sulphide. 5-Methylthionaphthene[3] and 6-methylthionaphthene[4] have been prepared by the reduction of the corresponding 3-hydroxy-methylthionaphthene. With a view to illustrate the scope of the new synthesis of thionaphthene, 5-methyl-(II) and 6-methylthionaphthene (IV) and the hitherto unreported 7-methylthionaphthene (VI) have been prepared. Another object was to determine the ease of cyclization of *o*-, *m*- and *p*-tolyl ω-dimethoxyethyl sulphides.

5-Methylthionaphthene (II) was prepared by the cyclization of *p*-tolyl ω-dimethoxyethyl sulphide (I). It is a colourless crystalline solid, m.p. 37–38°, whereas Tarbell, *et al.*[3] have described the same product as a colourless liquid. Weissgerber[5] has isolated two methylthionaphthenes, m.p. 36° and m.p. 52°, from crude methylnaphthalene. On the basis of m.p., these are probably identical with 5-methylthionaphthene (II), m.p. 37–38°, and with 2-methylthionaphthene, m.p. 52°, respectively. 6-Methylthionaphthene (IV), colourless liquid (solidifies on cooling in ice), b.p. 110–115° (bath temp.)/4 mm. (picrate m.p. 114–15°), was prepared by the cyclization of *m*-tolyl ω-dimethoxyethyl sulphide (III). Tarbell and Fukushima[4] describe (IV) as a colourless solid, m.p. 42–42·5° (picrate 114·5–15·5°). 7-Methylthionaphthene (VI) was obtained by the ring-closure of *o*-tolyl ω-dimethoxyethyl sulphide (V). On oxidation with hydrogen peroxide in acetic acid, (VI) gave 7-methylthionaphthene-1-dioxide (VII). The yields of (II), (IV) and (VI) were 57, 87 and 89% respectively in the crude state and 48·5, 42 and 53% after purification through the picrate. The lower yield of 6-methylthionaphthene (IV) is surprising in view of the activation of the

cyclization position, *p*- to the methyl group in (III). The higher yield, 48·5%, of (II) is also surprising because the cyclization position in (I) is *m*- to the *o*-*p*-directing-methyl group. In view of the considerable difference between the yields of crude and pure (IV), closer examination of crude (IV) obtained after cyclization of (III) will be carried out, to find out if 4-methylthionaphthene is also formed by cyclization of (III).



None of the monohalogenothionaphthenes except 3-bromothionaphthene[6] has been described so far. 5-Chloro-(IX), 6-chloro-(XI) and 7-chloro-thionaphthenes (XIII) have now been synthesized as an extension of the thionaphthene synthesis and also as intermediates for further syntheses. Cyclization of *p*-chlorophenyl ω-dimethoxyethyl sulphide (VIII), of *m*-chlorophenyl ω-dimethoxyethyl sulphide (X) and of *o*-chlorophenyl ω-dimethoxy ethyl sulphide (XII) gave 5-chloro-(IX), 6-chloro-(XI) and 7-chloro-thionaphthenes (XIII) respectively. The yields of (IX), (XI) and (XIII), after purification through the picrate, were 43, 32 and 41% respectively. As in the corresponding 5-methylthionaphthene (II), the yield (43%) of 5-chlorothionaphthene was surprisingly more than 6-chlorothionaphthene (yield, 32%).



Experimental

(M.p. are uncorrected. Microanalyses by Drs. Weiler and Strauss and Mr. T. S. Gore.)

The intermediate sulphides (*S*-arylthioglycolic-aldehyde dimethyl acetals) and the corresponding thionaphthenes obtained by the cyclization of the sulphides have been prepared according to the general procedure outlined earlier.[7] The sulphides were characterized by the preparation of 2:4-dinitrophenylhydrazones of the parent *S*-arylthioglycolic-aldehydes and the thionaphthenes by the preparation of picrates.[7] The picrates were obtained in the analytical purity by mixing a solution of the pure thionaphthene and pure picric acid (slight excess over theory for mono-picrate) in absolute alcohol, concentration and cooling.

p-*Tolyl ω-dimethoxyethyl sulphide* (*I*)

p-Thiocresol[8] (13·5 g.), sodium (2·5 g.), bromoacetaldehyde dimethyl acetal (19·8 g.) and absolute alcohol (50 c.c.) were refluxed for 3 hours. The sulphide gave a straw-coloured liquid (15·1 g.; yield 65%). A portion was distilled thrice and finally collected at 170–75° (bath temp.)/15 mm. (Found: C, 61·9; H. 7·5. $C_{11}H_{16}O_2S$ requires C, 62·3; H, 7·6%). 2:4-*Dinitrophenylhydrazone* gave orange needles from alcohol, m.p. 108–9° (Found: N, 15·9. $C_{15}H_{14}N_4O_4S$ requires N, 16·2%).

5-*Methylthionaphthene* (*II*)

The above sulphide (7·8 g.) was added to phosphorus pentoxide (32·0 g.) and phosphoric acid (20·0 c.c.) at 160–70°/2 mm., when a pale yellow liquid was obtained (3·1 g.; yield 57%). On cooling the liquid gave a colourless solid. It was treated with picric acid (7·2 g.) in absolute alcohol and the picrate obtained was decomposed with 2% ammonia. 5-Methylthionaphthene (2·1 g., yield 48·5%) was isolated with ether and gave a white crystalline solid with naphthalene-like odour. It was further purified by distillation, m.p. 37–38°, b.p. 125–35° (bath temp.)/3 mm. (Found: C, 72·6; H, 5·5. Calc. for C_9H_8S: C, 73·0; H, 5·4%). The *picrate* gave yellow needles from absolute alcohol, m.p. 108–9° (Found: N, 10·4. Calc. for $C_{15}H_{11}N_3O_7S$: N, 11·2%).

m-*Tolyl ω-dimethoxyethyl sulphide* (*III*)

m-Thiocresol (7·6 g.), prepared according to Tarbell and Fukushima,[9] sodium iodide (0·92 g.), bromoacetal (10·4 g.), and absolute alcohol (50 c.c.) were boiled for 2 hours. The sulphide gave a colourless liquid, b.p. 148–150°/6 mm. (9·0 g., yield 69%). A portion was redistilled thrice and finally collected at 135–45° (bath temp.)/5 mm. (Found: C, 62·9; H, 7·7.

$C_{11}H_{16}O_2S$ requires C, 62·3; H, 7·6%). 2:4-*Dinitrophenylhydrazone* gave lustrous orange needles from alcohol, m.p. 95–96° (Found: N, 16·0. $C_{15}H_{14}N_4O_4S$ requires N, 16·2%).

6-*Methylthionaphthene* (*IV*)

The foregoing sulphide (2·6 g.) was added to phosphorus pentoxide (10 g.) and phosphoric acid (6 c.c.) at 175–80°/4 mm. The crude product (1·58 g.) was treated with picric acid, the picrate was decomposed by treatment with 5% sodium hydroxide and 6-methylthionaphthene (0·76 g., yield 42%) was isolated by steam distillation, and purified by two redistillations, when it was obtained as a colourless liquid which solidifies at low temperatures and has naphthalene-like odour; b.p. 110–15° (bath temp.)/4 mm. (Found: C, 73·1; H, 5·7. Calc. for C_9H_8S: C, 73·0; H, 5·4%). The *picrate* gave felted yellow needles from alcohol, m.p. 114–15° (Found: N, 11·8. Calc. for $C_{15}H_{11}N_3O_7S$: N, 11·2%).

o-*Tolyl ω-dimethoxyethyl sulphide* (*V*)

o-Thiocresol (8·6 g.), prepared from *o*-toluidine (*cf.*, preparation of *m*-thiocresol[9]), sodium (1·6 g.), bromoacetal (12·5 g.) and absolute alcohol (50 c.c.) were refluxed for 3 hours. The sulphide gave a colourless liquid (10·2 g., yield 69%), b.p. 155–60° (bath temp.)/6 mm. A portion was redistilled thrice and finally collected at 142–45° (bath temp.)/6 mm. (Found: C, 62·1; H, 7·8. $C_{11}H_{16}O_2S$ requires C, 62·3; H, 7·6%). 2:4-*Dinitrophenylhydrazone* gave lustrous yellow-orange needles from alcohol, m.p. 123–24° (Found: N, 15·6. $C_{15}H_{14}N_4O_4S$ requires N, 16·2%).

7-*Methylthionaphthene* (*VI*)

The foregoing sulphide (6·62 g.) was added to phosphorus pentoxide (27 g.) and phosphoric acid (17 c.c.) at 170–80°/4 mm. when a colourless oil (4·1 g., yield 89%) was obtained. It was treated with picric acid (7·0 g.) in absolute alcohol and the picrate obtained was decomposed by treatment with 2% ammonia. The colourless thionaphthene possessing naphthalene-like odour (2·45 g., yield 53%) was distilled, b.p. 110–15° (bath temp.)/4 mm. (Found: C, 72·5; H, 5·2. C_9H_8S requires C, 73·0; H, 5·4%). The *picrate* gave elongated golden yellow needles from absolute alcohol, m.p. 144–45° (Found: N, 10·9. $C_{15}H_{11}N_3O_7S$ requires N, 11·2%).

7-*Methylthionaphthene*-1-*dioxide* (*VII*)

The thionaphthene (0·4 g.) was reacted with glacial acetic acid (6 c.c.) and hydrogen peroxide 100 vols. (2 c.c.) on water-bath at 85° for 6 hours. The reaction mixture was poured into crushed ice. After neutralization

with potassium carbonate, 7-methylthionaphthene-1-dioxide (0·21 g.) was isolated by means of ether. It crystallises from aqueous alcohol in colourless flat needles, m.p. 74–75° (Found: 60·0; H, 4·5%. $C_9H_8O_2S$ requires C, 60·0; H, 4·4%).

The chlorothiophenols required in the following experiments were prepared from the corresponding chloroanilines by the method used for the conversion of *m*-toluidine to *m*-thiocresol.[9]

p-*Chlorophenyl ω-dimethoxyethyl sulphide* (*VIII*)

p-Chlorothiophenol (16·5 g.), sodium (2·7 g.), bromoacetal (21 g.) and absolute alcohol (50 c.c.) were refluxed for 4 hours. The sulphide gave a yellow liquid, b.p. 130–60°/15 mm. (18·5 g.; yield 69%). It was redistilled four times and finally collected at 155° (bath temp.)/12 mm. (Found: C, 51·1; H, 5·2. $C_{10}H_{13}ClO_2S$ requires C, 51·6; H, 5·6%). 2:4-*Dinitrophenylhydrazone* gave yellow orange needles from ethyl acetate-alcohol, m.p. 138° (Found: N, 14·9. $C_{14}H_{11}ClN_4O_4S$ requires N, 15·3%).

5-*Chlorothionaphthene* (*IX*)

The above sulphide (10 g.) was added to phosphorus pentoxide (50 g.) and phosphoric acid (30 c.c.) at 160–80°$_{110}$ mm. and the colourless liquid thionaphthene (3·1 g., yield 43%) obtained was distilled four times. It was steam-distilled and the product was further purified by two redistillations, b.p. 85° (bath temp.)/4 mm. (Found: C, 56·1; H, 3·1. C_8H_5ClS requires C, 57·0; H, 3·0%). The *picrate* crystallized in long yellow needles from absolute alcohol, m.p. 69–70° (Found: N, 10·1. $C_{14}H_8ClN_3O_7S$ requires N, 10·6%).

m-*Chlorophenyl ω-dimethoxyethyl sulphide* (*X*)

m-Chlorothiophenol (13·2 g.), sodium (2·25 g.), bromoacetal (17·0 g.) and absolute alcohol (50 c.c.) were boiled for 3 hours. The sulphide gave a yellow liquid, b.p. 100–80°/15 mm. (17·5 g., yield 65%). It was redistilled and the fraction boiling at 173°/44 mm. was collected and further purified by four redistillations, b.p. 170° (bath temp.)/15 mm. (Found: C, 51·3; H, 5·4. $C_{10}H_{13}ClO_2S$ requires C, 51·6; H, 5·6%). 2:4-*Dinitrophenylhydrazone* gave orange needles from ethyl acetate-alcohol, m.p. 123° (Found: N, 15·1. $C_{14}H_{11}ClN_4O_4S$ requires N, 15·3%).

6-*Chlorothionaphthene* (*XI*)

The foregoing sulphide (7·0 g.) was added to phosphorus pentoxide (35 g.) and phosphoric acid (21 c.c.) at 180–200°/15 mm., when a yellow liquid (3·8 g., yield 75%) was obtained. It was treated with picric acid

(5·5 g.), the picrate decomposed by 2% ammonia and the mixture extracted with ether. On removal of ether, the thionaphthene (1·6 g., yield 32%) was obtained as a colourless liquid having naphthalene-like smell. It was redistilled four times and finally collected at 125° (bath temp.)/15 mm. (Found: C, 56·7; H, 3·1. C_8H_5ClS requires C, 57·0; H, 3·0%). The *picrate* gave yellow needles from absolute alcohol, m.p. 134° (Found: N, 9·8. $C_{14}H_8ClN_3O_7S$ requires N, 10·6%).

o-*Chlorophenyl ω-dimethoxyethyl sulphide* (*XII*)

o-Chlorothiophenol (10·4 g.), sodium (2 g.), bromoacetal (15 g.) and absolute alcohol (50 c.c.) were boiled for 4 hours. The sulphide gave a colourless liquid, b.p. 190–200° (bath temp.)/25 mm. (10·4 g., yield 62%). It was redistilled four times and finally collected at 170° (bath temp.)/10 mm. (Found: C, 51·5; H, 5·2. $C_{10}H_{13}ClO_2S$ requires C, 51·6; H, 5·6%). 2:4-*Dinitrophenylhydrazone* gave yellow orange needles from ethyl acetate-alcohol, m.p. 135–36° (Found: N, 15·2. $C_{14}H_{11}ClN_4S$ requires N, 15·3%).

7-*Chlorothionaphthene* (*XIII*)

The above sulphide (7·35 g.) was added to phosphorus pentoxide (37 g.) and phosphoric acid (25 c.c.) at 160–70°/10 mm., when a pale yellow liquid (2·15 g., yield 40%) was obtained. It was redistilled four times and finally collected at 115° (bath temp.)/10 mm. (Found: C, 56·9; H, 3·2. C_8H_5ClS requires C, 57·0; H, 3·0%). The *picrate* gave long lemon-yellow needles, from absolute alcohol, m.p. 141–42° (Found: N, 10·8. $C_{14}H_8ClN_3O_7S$ requires N, 10·6).

Summary

5-Methyl- (II) and 6-methyl-thionaphthenes (IV) and the hitherto unknown 7-methyl-(VI), 5-chloro-(IX), 6-chloro-(XI) and 7-chloro-thionaphthenes (XIII) were prepared by the new synthesis. 7-Methylthionaphthene-1-dioxide (VII) was also prepared.

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A NEW TECHNIQUE FOR RUBIN NUMBERS

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Introduction

'Gold Number' originated by Zsigmondy[1] gives a measure of the protective action of a hydrophilic colloid. In view of the difficulties in the preparation of the Zsigmondy red gold sol and also the elaborate methods of standardisation necessary with other gold sols, Ostwald's[2] 'Rubin Numbers' can be used with advantage in the place of gold number. Subramhanya and others[3] have studied in detail the technique of rubin numbers and have found that a pH of 5·1 to 5·3 gives best results. Though their technique employing the pH colorimeter is a distinct improvement over the original procedure of Ostwald with regard to precision, careful study of the method has revealed certain defects. The new technique presented in this paper has been developed by overcoming these defects.

Experimental

1. *Materials used.*—(i) Congo rubin: congo rubin of purity 99·5% is obtained by purifying the Kahlbaum product by the method employed by Doss[4] for benzopurpurin 10B. The purity has been determined by finding out the percentage of sulphated ash.

(ii) The buffer solution of pH 5·1 is prepared[5] from sodium acetate and acetic acid, the pH being determined by the quinhydrone electrode.

(iii) Starch and albumin are pure products of Kahlbaum and Merck respectively.

(iv) Casein: The Kahlbaum product is dissolved in 0·1 N NaOH and the solution made up after exactly neutralising the alkali with acid.

2. *Procedure.*—5 c.c. of 0·004% aqueous solution of congo rubin is mixed with 0·5 c.c. of the buffer of pH 5·1 and the required quantity of the protective colloid. The mixture is made up to 10 c.c. with water and allowed to stand for 3 minutes. 1 c.c. of 10% sodium chloride in water is then added and the mixture heated to a temperature of 60° C. for 10 minutes and cooled to room temperature. The solution is then centrifuged to remove the blue dye in suspension and the red colour of the centrifugate is measured by the

Lovibond Tintometer, using a 0·6″ cell. In actual practice, double the quantities have been used for the determination.

The results are given in Tables I, II, III and IV and Figs. 1, 2 and 3. The method of calculating the rubin numbers from the above data is discussed in the next section.

TABLE I. *Casein*

Mg. of casein in 10 c.c. of solution	Colour of centrifugate : Red in Lovibond units
0·0	2·9
0·2	3·7
0·3	4·4
0·4	5·1
0·5	6·2
0·6	6·7
0·7	7·5
0·8	8·6
1·0	12·8
2·0	13·4
2·5	14·0
3·0	14·3
Colloid and no salt	15·0

TABLE II. *Albumin*

Mg. of albumin in 10 c.c. of solution	Colour of centrifugate : Red in Lovibond units
0·0	2·9
0·5	3·1
1·0	3·7
1·5	5·6
2·0	8·9
2·5	9·4
3·0	9·6
4·0	9·8
Colloid and no salt	9·8

TABLE III. *Starch*

Mg. of starch in 10 c.c. of solution	Colour of centrifugate : Red in Lovibond units
0	2·9
5	3·4
20	4·8
30	5·2
40	5·7
50	7·2
70	8·0
90	8·9
100	9·7
140	12·0
Colloid and no salt	15·0

TABLE IV

Colloid	Rubin Nnmber by the new method	Rubin Number Subramhamya, Doss & Rao	Gold Number[7]
Starch ..	91	31	25
Casein ..	0·82	0·66	0·01
Albumin ..	2·1	2·5	0·09

Discussion

1. *The method of Subramhanya, Doss and Rao.*—The rubin number of a protective colloid, as defined by the above authors, is the number of milligrams of that colloid which when present in 10 c.c. of 0·002% congo rubin solution of pH 5·2 produces 26·5% blue colour on addition of 1 c.c. of 10% sodium chloride. An attempt was made by the present authors to apply this method for determining the hydrophilic colloid content of sugars and sugar products. In the course of the work, it has been observed, in conformity with earlier observations[6] that the mixture obtained by the addition of sodium chloride contains a coarse precipitate in suspension. As colour measurements of such systems are difficultly reproducible, it is felt desirable to remove the precipitatte before measuring the colour.

2. *Principle of the New Technique for the Rubin numbers.*—Two methods are possible for the removal of the dye in suspension: (1) filtration and (ii) centrifuging. Adsorption of the dye on the filter-paper from solution has been found to lead to irreproducible results in the first method. Hence the second method is resorted to. The centrifugate however, is found to be invariably free from the blue colour presumably due to the blue substance being entirely in the form of a coarse precipitate. It is therefore, not possible to base the determination of the rubin number on the blue colour developed. The intensity of the red colour in the centrifugate, however, depends upon the nature and the quantity of the hydrophilic colloid present. When there is no protective action, the centrifugate is of very light colour corresponding to the solubility of rubin in the medium consisting of the buffer and the sodium chloride. As the protective action comes progressively into play, the rubin gets solubilised and the intensity of the red in the centrifugate increases. Thus the intensity of the red colour can be taken as a measure of its protective action. To bring about a quick interaction between the sodium chloride and the dye-hydrophilic colloid system, it is found desirable to heat the mixture to about 60° C. and cool to room temperature before centrifuging. Only in the case of albumin, care is taken not to heat the solution above 50° C. to minimise denaturation.

3. *Rubin numbers of starch, casein and albumin.*—An examination of Table I shows that the residual colour of the centrifugate of the mixture containing salt but no protective colloid is 2·9 units (red). In presence of increasing quantities of starch, the residual colour increases and tends to reach a value of 15·0 units (red) at the highest concentrations. This asymtotic limit is experimentally determined by finding the colour of a system containing the dye, buffer and the starch but no salt. If with zero concentration

of the protective colloid the colour is X units and with infinite concentration the colour should be Y units, then the rubin number can be defined as the number of milligrams of colloid necessary for obtaining a residual colour of $\frac{X+Y}{2}$ units, *i.e.*, $\frac{2{\cdot}9+15{\cdot}0}{2}$ or 9·0 units. The rubin number for starch on this basis works out to be 91. It can be seen from Fig. 1, that the curve rises more or less linearly with the concentration of starch.

The rubin number of casein worked out on the above basis is 0·82. It is interesting to note that the curve in Fig. 2 rises steeply at the region corresponding to 9 units which incidentally enables an accurate determination of the rubin number.

The rubin number for albumin, corresponding to 9 tintometric units of red colour in the centrifugate comes out to be 2·1. In this case however, there is a complication arising from denaturation of albumin, in spite of the care taken not to allow the temperature of the solution to go above 50° C. The residue on centrifuging is not pure blue as in the other cases but has a reddish tinge, its intensity depending upon the amount of the albumin used. With larger amounts of albumin, the precipitate settled in the centrifuge tubes is red in colour. (It may be pointed out that with large amounts of other protective colloids there would be no sediment on centrifuging.) Owing to this, the maximum residual colour obtained with albumin is only 9·8 units, as compared with the theoretical 15·0 units.

An examination of Table IV shows that the rubin numbers determined as herein described show the same trend as those obtained by the earlier methods.

4. *Mechanism of interaction between the hydrophilic colloids and rubin.*— The interaction equilibrium between the protective colloid P and rubin R may be provisionally formulated as follows:—

$$P + nR \rightleftharpoons PR_n.$$

Applying Law of Mass Action (using concentrations instead of activities) we get

$$\frac{[PR_n]}{[P]\,[R]^n} = k_1.$$

Since solid rubin would be present at equilibrium one can put [R] constant,

$$\therefore \quad [PR_n] = k_2[P]$$

Thus the amount of solubilisation of rubin brought about by the hydrophilic colloid would be proportional to the concentration of the free protective colloid. But since only a small fraction of the latter would be present as complex the solubilisation would be proportional to the total concentration of the protective colloid. Thus the intensity of red colour in the centrifugate would be a rectilinear function of the concentration of the colloid. This explains very well the behaviour of starch as seen from Fig. 1. A departure from linearity can, however, be expected at very high concentrations of starch, at which the solubilisation may be very high and the solid rubin phase may disappear.

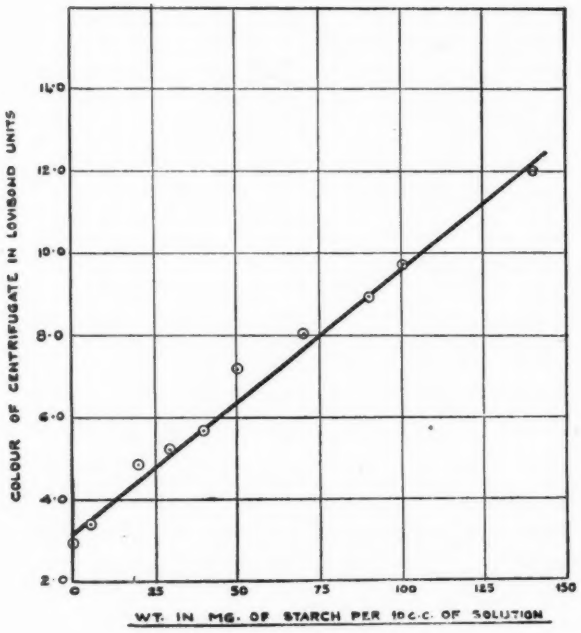

FIG. 1. Starch

With casein and albumin, however, it is seen that the curve is of S shape (Figs. 2 and 3). But, the above simple formulation ignores the effects due to factors such as electric charge and micelle formation. It is a matter of great interest from the point of view of the mechanism of interaction between hydrophilic colloids and the dye to investigate the cause of the great dissimilarity in the curves obtained with the different protective colloids.

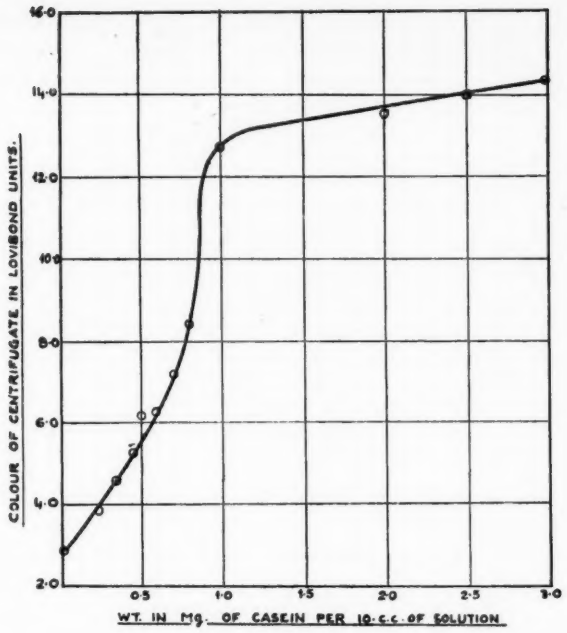

FIG. 2. Casein

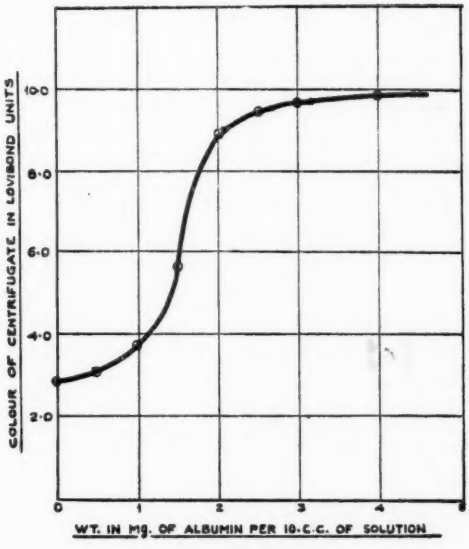

FIG. 3. Albumin

The authors wish to thank Prof. J. M. Saha, Director, Indian Institute of Sugar Technology, Kanpur, for his kind interest.

Summary

A new method for the determination of rubin numbers has been advanced. The previous method based on the measurement of the blue colour was discarded as the blue dye was found to be in suspension. The rubin number of a protective colloid is defined as the number of milligrams of that colloid which when present in 10 c.c. of 0·002% congo rubin solution of pH 5·1 produces 9·0 Lovibond units of red colour in a 0·6″ cell on addition of 1 c.c. of 10% sodium chloride and centrifuging. The results obtained by this method in the case of starch, casein and albumin show the same trend as the results of the earlier methods.

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THE SUPPLEMENTARY NUTRITIVE VALUE OF COCONUT CAKE (*COCOS NUCIFERA*)

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During the period preceding World War II, the western part of the Madras Presidency in India was mainly dependent on Burma for its supplies of rice to supplement what was available on that Coast. With the occupation of Burma and the neighbouring countries by the Japanese, these supplies were completely cut off with the result that tapioca (*Manihot utilissima*) came into much greater use as food than at any time before. With the present continued shortage of food grains, this article of food still continues to be the staple food of majority of the people in these areas.

Karunakaran[1] in his report to the Technical Commission on Nutrition of the League of Nations, stated that tapioca had come into greater use as a staple food in the couple of decades preceding the date of his report and that this was due to pressure of population on land. He estimated that if tapioca were the staple food, the energy requirements of an adult man per year could be met from 0·2 to 0·4 of an acre of land whereas 0·76 to 1·45 acre respectively would be required if potatoes or wheat were the staple food. The average yield of tapioca per acre is about two to 5 tons. He added that "tapioca has undoubtedly helped the people to escape famine and the privations which have affected other parts of India, but it has at the same time accounted for the progressive deterioration in the physique and an increased incidence of disease of various kinds". In 1943–44, the production of tapioca increased by about 33 per cent. and was placed at about 750,000 tons. In the Cochin State, and the districts of Malabar, the area was almost doubled (Sreeramamurthy[2]). Thus, tapioca is a food crop of growing importance.

Krishnan[3] observed that children living in a tapioca-producing area were smaller and lighter in build at all ages than rice-eating children in other parts of India. It has been estimated that about 75 per cent. of the population of Travancore was consuming tapioca in various forms. No data are available for other parts of the West Coast. Aykroyd and Krishnan[4] in studying the supplementary nutritive value of various protein-rich foods when added to a tapioca diet, observed that dried yeast, pulses or soyabean did not improve the growth rate of rats to any appreciable extent but that casein at a 6 per cent. level of intake brought about an average weekly growth rate of 5·9 grams. They concluded that the defect of a tapioca diet may

be due to the quantity and probably also the quality of the protein in it. The low protein content of tapioca is well known; animals on a tapioca diet alone soon lost weight and died during the period of experiment. Sreeramamurthy[2] studied in detail the nutritive value of tapioca and the quality of protein in it. He came to the conclusion that the protein contains a fair distribution of the essential amino acids and that therefore, the defect is due only to the low protein content. Therefore, then, a supplement of a protein-rich material should correct the defects of the tapioca diet. Swaminathan[5] reported a biological value of 77 for coconut proteins and observed that in general, the proteins of nuts, and oilseeds are superior to those of pulses. John, Finks and Gersdorff[6] observed in their feeding experiments that coconut proteins supplied most of the important amino acids. Sherman[7] placed coconut protein on an almost equal footing with the proteins of egg, meat, fish, etc., and recommended its use as a supplement to the cereal diet in view of the relatively low lysine content of grain proteins and the higher lysine content of coconut proteins.

Animal experiments were, therefore, carried out to assess the value of coconut cake (defatted coconut meal) as a supplement to the "poor rice" diet and the tapioca diet.

Experimental

Rats weighing about 50 grams and 4 to 5 weeks old were divided into groups of 6 each with an equal distribution between the sexes in the groups. The poor rice diet used in these experiments had the following composition (Aykroyd, Krishnan, Passmore and Sundararajan[8]):—

	Grams
Rice, raw	596
Dhal Arhar (*Cajanus indicus*) ..	20
Black gram (*Phaseolus mungo*) ..	20
Brinjals (*Solanum melongena*) ..	28
Amaranth leaves (*Amaranthus gangeticus*)	14
Raw plantain (*Musa paradisciaca*) ..	14
Gingelly oil (*Sesamum indicum*) ..	3
Coconut, fresh (*Cocos nucifera*) ..	1·4
Meat (Mutton)	1·7

This diet supplied about 45 to 47 grams protein working to about 6·7 per cent. This diet has been worked out as a result of diet surveys made among the poorer classes of South India and used extensively on work of similar nature in the Nutrition Research Laboratories, Coonoor. While the first group of rats was fed the poor rice diet, the second, third and fourth groups

received 10, 20 and 30 per cent. respectively of coconut cake in the place of an equal quantity of rice. The rats were fed the cooked diet *ad libitum* and the experiment was run for a period of eight weeks. The animals were weighed every week and the results are shown in Table I and graphically

TABLE I

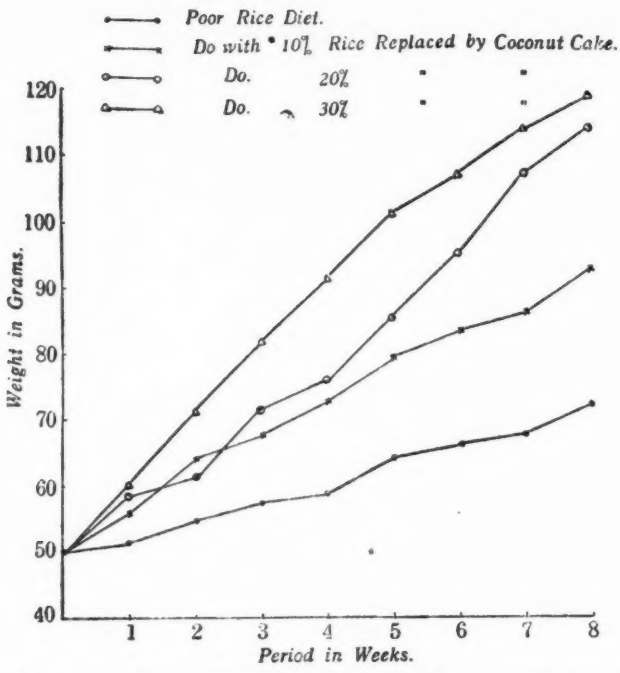
Value of coconut cake as a supplement to poor rice diet

Diet	Protein in diet %	Initial weight of rats gm.	Final weight of rats gm.	Average weekly increase in weight of rats gm.
1. Poor rice diet ..	6·7	49·5	72·0	2·8 ± 0·14
2. Do. with 10 per cent. of rice in diet replaced by coconut cake ..	8·26	49·5	93·0	5·4 ± 0·98
3. Do. with 20 per cent. of rice in diet replaced by coconut cake ..	9·66	49·5	113·5	8·0 ± 0·84
4. Do. with 30 per cent. of rice in diet replaced by cocoanut cake ..	11·14	49·5	118·5	8·6 ± 0·70

in Fig. 1. It will be seen from these results that coconut cake added to a poor rice diet has a beneficial effect on growth rate of rats at all the levels investigated.

For the experiments on the value of coconut as a supplement to the tapioca diet, the basal diet was modified in certain respects so as to correspond to the conditions prevailing on the West Coast of the Madras Presidency at the present time. Thus, rice in the poor rice diet was replaced by dried, powdered tapioca and pulses were omitted for the reason that during the present food shortage, they were not available in even inadequate quantities and that when available, they were far too costly for the poorer classes to afford them. Though this applies to meat and fish also, meat was included in the experimental diets to correspond to what little of it they may consume occasionally. Thus, the diet, as used in these investigations, had the following composition:

	Grams
Tapioca (dried)	91·0
Brinjal	4·0
Amaranth leaves	2·0
Plantain, raw	2·0
Meat, (Mutton)	0·5
Coconut oil	0·5



TEXT-FIG. 1. The supplementary effect of coconut cake on a 'poor rice' diet.

The experimental details were the same as described earlier, but the second and third groups received coconut cake at 30 per cent. level in the place of an equivalent amount of tapioca. The rats of the third group received a supplement of calcium in the form of calcium carbonate during the first four weeks of experiment and thereafter, an equivalent of calcium lactate (0·4 gram Ca per cent.). The calcium supplement was made because it was found by analysis that the calcium content of the diet itself and after substitution with 30 per cent. coconut cake was low and not in proportion to the phosphorus content. This was especially so in the supplemented diet of the second group. The protein, calcium and phosphorus contents of the diets are shown in Table II.

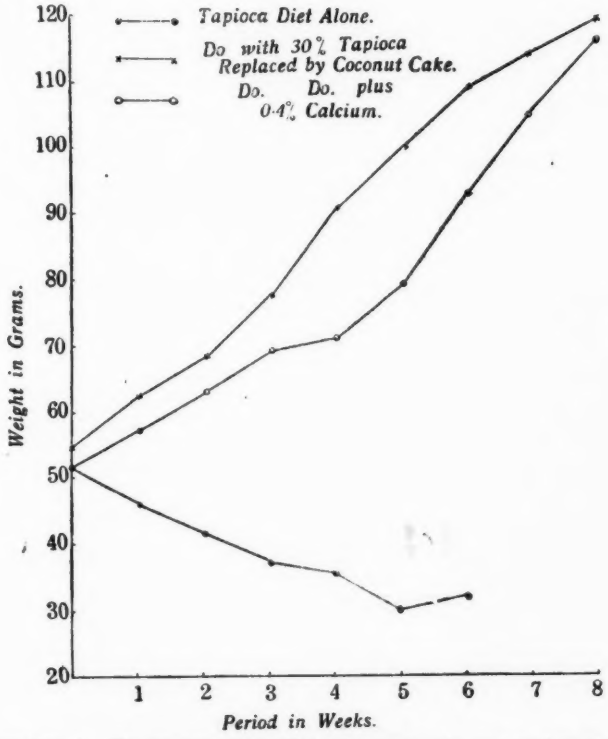
During the first four weeks of the experiment, when calcium carbonate had been added to the third group, it was observed that the rats did not grow as satisfactorily as was to be expected and therefore, from the commencement of the fifth week of the experiment, calcium lactate in equivalent quantity was added in the place of calcium carbonate.

TABLE II

The protein, calcium and phosphorus contents of diets based on tapioca

Diet	Protein %	Calcium %	Phosphorus %	Ca/P
1. Modified tapioca diet ..	2·258	0·064	0·057	1·13
2. Do. with coconut cake at 30 per cent. level ..	9·713	0·078	0·200	0·39
3. Do. with coconut cake at 30 per cent. level *plus* calcium supplement (0·4 per cent.) ..	9·931	0·324	0·179	1·82

Thereafter, growth improved till at the close of the experiment (eighth week) the average final body weight of this group of rats approximated that of Group 2 (Fig. 2).



TEXT-FIG. 2. The supplementary effect of coconut cake on a tapioca diet.

It is to be seen from the figure that rats on tapioca diet alone quickly lost weight and died in about six weeks while the animals in other groups showed an average weekly increase in weight of about 8 grams.

It was mentioned earlier in this paper that children living in tapioca-producing areas were smaller and lighter in body build at all ages than rice-eating children in other parts of India (Krishnan).[3] It would therefore be of interest to find out if coconut supplements with and without extra calcium will help in increasing the weight of bones in rats. Therefore, at the close of the experiment (in Group 1 when the rats died), the femurs of the rats were collected, fat extracted with ether-alcohol mixture and dried to constant weight. The ash content, calcium and phosphorus in the bones were also determined. The results are presented in Table III, from which it will be

TABLE III

Value of coconut cake as a supplement to a tapioca diet

Diet	Average initial weight of rats	Average final weight of rats	Average weekly increase in weight of rats	Average dry weight of femurs	Ash content of bones	Total calcium (Ca)	Total phosphorus (P)	Ca/P
	gm.	g m.	gm.	gm.	%	mg.	mg.	
1 Modified tapioca diet	52·0	32·0*	−3·3 ±0·35	0·0872 ±0·017	31·21 ±2·41	14·90 ±5·10	6·68 ±1·68	2·23
2 do. with 30 per cent. of tapioca replaced by coconut cake	54·5	119·0	8·06 ±0·70	0·3545 ±0·012	36·82 ±0·40	49·3 ±1·20	25·2 ±1·49	1·96
3 do. with 30 per cent. of tapioca replaced by coconut cake *plus* calcium (0·4 per cent.)	52·0	115·0	8·0 ±0·89	0·4075 ±0·021	43·99 ±0·53	72·4 ±4·65	31·6 ±1·64	2·29

* All the rats in this group died by the end of the sixth week of experiment.

seen that the percentage of ash in the bones is greater when the coconut supplement is made and more so when calcium is also added to this supplement.

DISCUSSION

The value of coconut cake when combined with the poor rice diet, though not so markedly brought out as in the case of tapioca diet, is clearly seen in that it causes an increased growth rate of about 5·8 grams per week over the control when the cake replaces 30 per cent. of the rice in the diet. The average weekly increase in weight when coconut cake replaces 30 per cent. of the rice or tapioca as the case may be, appears to be almost the same.

As a supplement to the tapioca diet, coconut cake showed a greater response. Thus, while rats could not be maintained on a tapioca diet alone

for more than five or six weeks, coconut cake at 30 per cent. level supplying about 8 grams extra protein per 100 grams of diet, improved the growth rate considerably (about 8 grams per week). Calcium supplements did not increase the growth rate in the present experiments, but probably, if calcium had been given in the form of calcium lactate right from the commencement of the experiment, there might have been an appreciable difference in favour of calcium supplement.

The growth rate in the case of coconut cake supplements compared favourably with that obtained by Aykroyd and Krishnan[4] with casein supplements almost at the same level of protein intake. The same authors[9] stated that even on an excellent stock diet, rats in Coonoor gain only 10·6 grams per week. In comparison with this, the growth rate of rats on tapioca diet supplemented with coconut cake at 30 per cent. level seems satisfactory.

The bones of rats on tapioca diet alone were very poorly developed and calcification was also poor. The percentage of ash in femurs was 31·2 for Group 1 while it was 36·6 and 44·0 for those of Groups 2 and 3 respectively. Though it is evident from the results that calcification was not the optimum in the third group of rats, calcium supplement had an ameliorative effect and this finds further confirmation in the results of analysis of bones for calcium and phosphorus.

Thus coconut by itself, considerably improves the nutritive value of both poor rice and tapioca diets and a further supplement of calcium to the tapioca diet tends to improve the mineralization of the bones.

Summary

Experiments have been carried out with a view to finding out the supplementary nutritive value of coconut cake when added to "poor rice" and tapioca diets. It was observed that a supplement of coconut cake at 30 per cent. level increased the weekly growth rate of rats as well as the weight and ash content of bones. Coconut cake can therefore be used as a supplement to "poor rice" and tapioca diets.

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ELECTRO-CHEMICAL REACTIONS IN ALTERNATING ELECTRIC FIELD

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1. Introduction

The study of kinetics of electro-chemical reactions under the action of alternating fields has assumed a new importance in view of the recent interesting work of Randles.[1] The work of Randles distinctly indicates the possibility of a chemical reaction being brought about by the action of alternating field with a considerably high current efficiency. Very little work however has been done on the quantitative measurement of current efficiency for electrolysis using alternating current. The only important detailed study of recent times is by A. N. Kappanna,[2] who has determined the current efficiency using silver nitrate as electrolyte. It is however found that there were complications due to the electrode surfaces being altered by the deposits produced by the current. Further, there was formation of silver peroxynitrate at one of the electrodes. The present work has been confined to the electrolysis of ferric sulphate solutions using platinum electrodes, wherein the electrode reactions are simpler in character.

2. Experimental

The alternating current was obtained through a transformer giving a voltage of 45 to 90 volts, current being adjusted using a rheostat. The peak current was measured by making use of an oscillograph, from which the average value of the current was computed. The average value was confirmed by making use of a rectifier type microammeter. 0·33N ferric sulphate was used as the electrolyte. Platinum wire electrodes were employed. In any electrolytic cell the two electrodes were nearly of the same dimensions, the average area being taken for the calculation of current density. In many of the experiments, a number of electrolytic cells were put in series so as to minimise the effects due to change in nature and magnitude of the quantity of electricity passed while interpreting the effect of dimensions of the electrodes on current efficiency. In all these experiments the net reaction was

that of reduction, the ferric salt being reduced to the ferrous state. Evolution of hydrogen and oxygen was noticed in every case except with the lowest current density (when platinum discs were used as electrodes).

In the present work the discharge of hydrogen has been ignored and the current efficiencies are all calculated on the basis of the amount of ferrous salt produced. Since the net reaction is found to be reduction, the current efficiency is calculated by taking into account the total amount of cathodic current passed and the actual amount of net reduction that has taken place. The amount of reduction was determined by titrating the resulting ferrous salt against standard (0·01 N) permanganate. The electrolysis was conducted for a duration of 5 minutes, 10 minutes and 15 minutes. Duplicates were performed in each case. The average of each of the 6 sets of values are given in Table I. Some experiments were conducted with boiling electrolyte. Values obtained by experiments for 15 minutes duration are given in Table I.

TABLE I

No.	Electrode Dimensions		Current Density Amps./sq. cm.	Current efficiency % at Room temperature	Current efficiency % at Boiling temperature
1	Dia.	Length	6·7	15	..
			3·4	17	21
	0·0152 cm.	0·65 cm.	1·7	4·5	22
			·83	4·3	23
			·42	4·1	17
2	0·0229 cm.	0·65 cm.	4·4	15	..
			2·2	7·8	22
			1·1	3·3	20
			0·55	4·0	25
			0·28	3·3	26
3	0·0356 cm.	1·1 cm.	1·7	4·4	..
			0·85	3·9	20
			0·42	3·1	18
			0·21	1·4	15
			0·11	1·9	8·6
4	0·0356 cm.	2·1 cm.	·88	5·6	..
			·44	4·9	17
			·22	3·9	13
			·11	2·9	9·3
			·055	3·1	7·0
5	Disc electrode each of area 3·5 sq. cm.		0·06	1·9	..
			0·03	1·3	3·2
			0·015	0·7	3·0
			0·008	0·5	3·3
			0·004	..	4·6

3. Discussion

The general results obtained in the preliminary investigation are as follows:—

Firstly it is found that the current efficiency for the net reduction reaction can be as much as 25% or even higher. Secondly there is a general parallelism between current densities and current efficiencies, the latter increasing with the increase of former. Finally experiments at the boiling temperature have yielded much higher current efficiencies than those obtained at the ordinary temperatures.

Let us picture the conditions at an electrode dipped in an electrolyte and subjected to the action of an alternating current. When the electrode experiences the cathodic half wave of the alternating current, reduction takes place and the reduction products are formed at the electrode. If these products are not removed by either phase separation or diffusion, there is a possibility of the reaction being reversed during the anodic half wave of the current. If the anodic half wave completely reverses the reaction brought about by the cathodic half wave, the net chemical reaction will be zero and the current efficiency as defined in this paper becomes zero. If however during the progress of reduction, the products of the reaction are partially removed by phase separation or diffusion, the anodic half wave will not have its full effect, especially as in these experiments when the original solution does not contain any oxidisable substance. The occurrence of a net electrochemical reaction is further favoured if the oxidative electrode process is slower than the reductive process under similar conditions.

Let us consider in a little detail the kinetics of the reduction process. During the cathodic half wave the electrode gets charged to higher and higher reductive potentials up to a maximum value after which the potential goes on falling to a zero value. According to the theory of Absolute Reaction Rates as applied to electrode processes,[3] the instantaneous rate of the reduction process would be a function of the potential of the electrode at that instant. With the rise in the potential, the rate of reduction would increase exponentially. One may expect therefore that at higher current densities which should normally mean higher peak potential, one would get larger accumulation of the products of reaction at the electrode which would bring about a larger extent of diffusion and hence increase the current efficiency with reference to the net reduction reaction. Further, with the increase in current density, the overvoltage of the electrode surface for hydrogen evolution would be greatly exceeded by the electrode potential and hence vigorous

evolution of hydrogen takes place. This evolution would cause vigorous stirring at the electrode surface, and the resulting convection process would facilitate the movement of products of the reaction. This would again cause increase in current efficiency. This explains the general observation that the current efficiency increases with current density. The higher current efficiencies met with in the experiments at high temperatures are to be attributed to the higher diffusion rate and lower overvoltage for discharge of hydrogen.

A careful examination of Fig. 1 shows that the current efficiency may not be a single-valued function of current density, particularly at high values of current. There appears to be a tendency for high current efficiency with larger electrodes even at the same current density. This phenomenon is being investigated and further work is in progress.

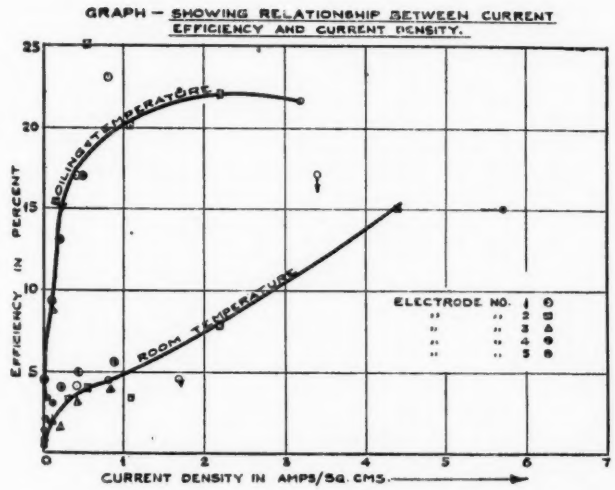

FIG. 1. Graph—Showing Reltionship between Current Efficiency and Current Density

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5. Summary

The reduction of ferric sulphate brought about by alternating current has been quantitatively studied. It is found that the current efficiency can be as much as 25% or even higher under favourable conditions. The current efficiency increases with increase in current density and rise in temperature. The results are qualitatively explained on the basis of the theory.

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SOME SOLUTIONS OF THE WAVE EQUATION

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1. For rectilinear boundaries a number of solutions of the two-dimensional wave equation

$$\nabla^2\phi = c^2 \frac{\partial^2\phi}{\partial t^2} \tag{1}$$

are known, in which the boundary condition satisfied by ϕ is

$$\phi = 0, \tag{2.1}$$

or

$$\frac{\partial\phi}{\partial n} = 0, \tag{2.2}$$

∂n denoting a normal element drawn to the boundary. In the transverse vibrations of membranes the condition (2.1) amounts to a fixed edge, and in Hydro-dynamics of inviscid liquids (2.2) is to be satisfied over a fixed boundary. Some such solutions satisfying (2.1) have been given by B. R. Seth.[1] For hexagonal and equilateral boundaries* incomplete solutions have been obtained by D. G. Christopherson[2] and B. B. Sen.[3] Christopherson's solution has been completed by P. N. Sharma.[4]

2. When the boundary condition is nonhomogeneous solutions of the wave equation for rectilinear boundaries have not received much attention, though formal solutions can be obtained through the Green's function. In a recent investigation of some problems in the bending of elastic plates it was required to determine solutions of (1) satisfying the boundary condition

$$\phi = k, \text{ a constant.} \tag{2.3}$$

It is proposed to give some of these solutions. It is found that for equilateral, some rhombus and pentagonal boundaries the solution can be obtained in a finite number of trigonometrical terms.

3. Assuming that $\theta \propto \cos(pt/c)$ we can rewrite (1) as

$$\nabla^2\phi + p^2\phi = 0. \tag{3.1}$$

* The complete solution for an equilateral boundary was originally obtained by Lamé in *Leçons sur l'Elasticite.*

A typical solution of (3·1) is

$$\phi = \begin{matrix}\sin\\ \cos\end{matrix}(p\sqrt{\cos\theta})\begin{matrix}\sin\\ \cos\end{matrix}(py\sin\phi). \tag{3·2}$$

It may be noted that when applied to the vibrations of a membrane the condition (2.3) means that its edge is vibrating harmonically.

4. For a rectangular section with sides $x = \pm a$, $y = \pm b$, we see that $k\cos px\sec pa$ satisfies the boundary condition (2·3) over $x = \pm a$. Using the Fourier's expansion for $\cos px$ which vanishes for $x = \pm a$, we get

$$\phi = k\left[\cos px\sec pa - \sum_{\bullet}^{\infty} A_n \sec b\sqrt{p^2-\alpha_n^2}\cos\alpha_n x\cos\sqrt{p^2-\alpha_n^2}\,y\right], \tag{4}$$

where $\alpha_n = (2n+1)\pi/2a$,

$$A_n = \frac{2(-1)^{n+1}kp^2}{a\alpha_n(p^2-\alpha_n^2)}.$$

For a right-angled isosceles triangular section with sides $x = a$, $y = a$, $y + x = 0$, we see that the functions to be used for the individual sides can be taken to be of the form $\sin px$, $\sin py$ and $\cos\frac{p}{\sqrt{2}}(x+y)$, respectively.

On account of the symmetry which exists about the line $y = x$ we now take two Fourier series which are such that their sum vanishes over $y = -x$ and in which terms can be obtained from one another by interchanging x and y. Thus we get

$$\begin{aligned}\phi = {} & k\cos\frac{p}{\sqrt{2}}(x+y) + \tfrac{1}{2}k(1-\cos pa\sqrt{2})\left[\frac{\sin px}{\sin pa} + \frac{\sin py}{\sin pa}\right] \\ & - \sum_{\bullet}^{\infty} A_n \operatorname{cosec} a\sqrt{p^2-\alpha_n^2}\left[\cos\alpha_n x\sin\sqrt{p^2-\alpha_n^2}\,y + \cos\alpha_n y\sin\sqrt{p^2-\alpha_n^2}\,x\right] \\ & - \sum_{\bullet}^{\infty} B_n \sec a\sqrt{p^2-\beta_n^2}\left[\sin\beta_n x\cos\sqrt{p^2-\beta_n^2}\,y + \sin\alpha_n y\cos\sqrt{p^2-\beta_n^2}\,x\right]\end{aligned} \tag{5}$$

where $\alpha_n = (2n+1)\pi/2a$, $\beta_n = n\pi/a$, and

$$A_n = \frac{(-1)^{n+1}kp^2\cos^2\frac{1}{2}pa\sqrt{2}}{a\alpha_n(\frac{1}{2}p^2-\alpha_n^2)},\quad B_n = \frac{(-1)^{n+1}k\beta_n p^2\sin^2\frac{1}{2}pa\sqrt{2}}{a(\frac{1}{2}p^2-\beta_n^2)(p^2-\beta_n^2)}.$$

For an equilateral section with sides $y = a$, $y = \pm x\sqrt{3}$, we should take functions of the type $\cos py$, $\sin py$, $\cos\frac{1}{2}px\sqrt{3}\cos\frac{1}{2}py$ and $\cos\frac{1}{2}px\sqrt{3}\sin\frac{1}{2}py$. It is found that no Fourier expansions are required, and we get

$$\begin{aligned}\phi = {} & k[2\cos\tfrac{1}{2}py\cos\tfrac{1}{2}px\sqrt{3} - \cos py] \\ & - k\cot\tfrac{1}{2}pa[2\sin\tfrac{1}{2}py\cos\tfrac{1}{2}px\sqrt{3} - \sin py].\end{aligned} \tag{6}$$

The result for a rhombus with sides $y = \pm x\sqrt{3} \pm 4\pi n/p$, n being an integer, can be readily deduced from (6) and we get

$$\phi = k\,[2\cos\tfrac{1}{2}py\cos\tfrac{1}{2}px\sqrt{3} - \cos py.] \qquad (7)$$

In like manner for a pentagonal section with sides $y = a$, $y = \pm x\sqrt{3} \pm 4\pi n/p$, the solution given in (6) holds good.

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	..	*See* Kao and others.
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